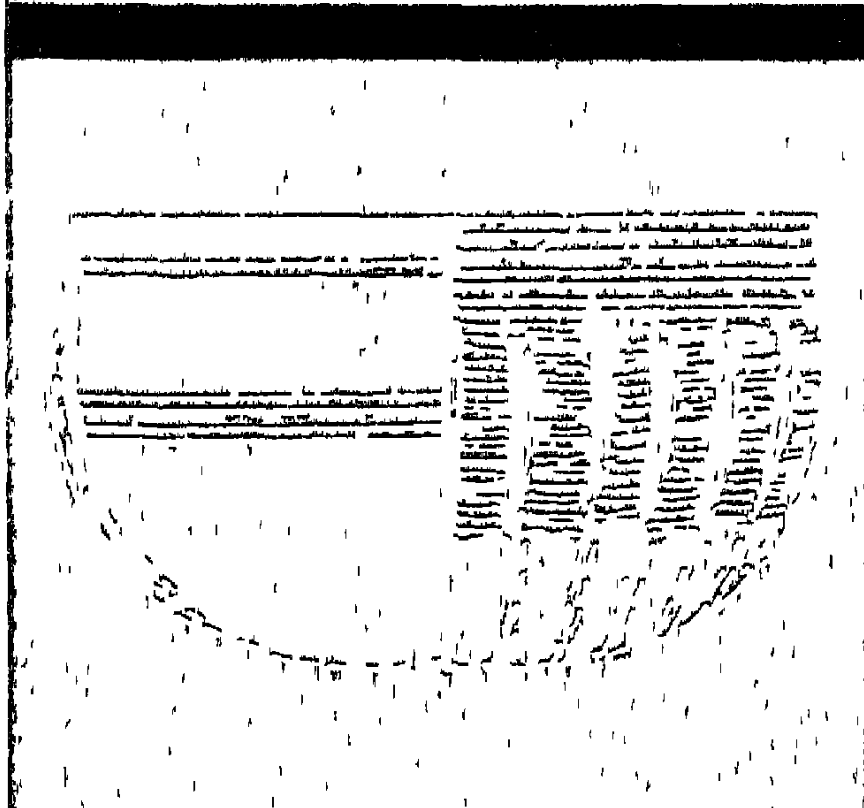
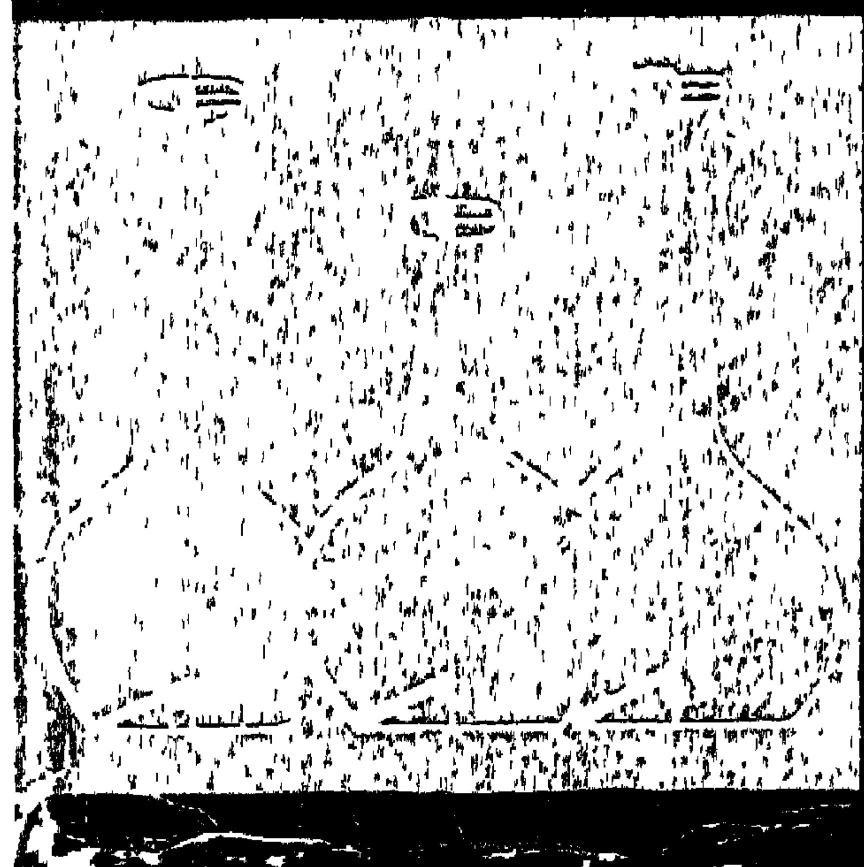

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ANCIENT GLASS AND INDIA

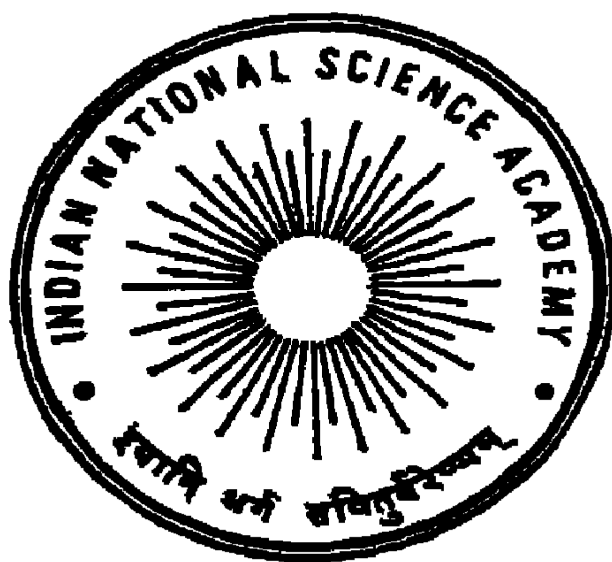


S. N. SEN
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FOREWORD

The monograph on Ancient Glass and India gives a fairly comprehensive account of the nature and properties of, and trade in, all kinds of glass and glass products belonging to the period from the second millennium B.C. to 14th century A.D. The specimens refer to samples collected throughout the world. They were mainly those upon which archaeological excavations could lay hands and which could be dated properly. The glass samples are generally those of containers of some kind or other, or parts of them, ornaments, beads and bangles, articles of decoration, rods and sheets. They are found to vary extensively in quality, shape, colour, etc. from one country to another and from one period to the other.

The major constituents of glass are the same, namely silica, lime and soda. A mixture of them in the appropriate proportions melts on heating and solidifies to a transparent or sometimes to an opaque material on cooling. The melting and cooling can be carried out any number of times, but the properties may change during such processes. A variety of other oxides are present in the mixture in small amounts and some in traces, either to impart special properties, such as opacity or transparency, to the products, or, most often, colours of varying kinds and degrees. These oxides are commonly one or more of the following elements: copper, manganese, iron, cobalt, antimony, titanium, lead, tin, barium, phosphorus, sulphur, aluminium, magnesium, potassium, etc.

Systematic and careful analyses of glass have been carried out by a number of investigators using chemical methods and sophisticated instruments. In the monograph these data have been compiled giving appropriate references and interpretations. Glass is an amorphous substance and apparently no stoichiometry amongst the major constituents exists.

Because of the ease of manipulating molten glass and its many unique properties, it attracted considerable attention of technicians, craftsmen, and scientists from the earliest times. From a comparative examination of the chemical compositions of glass of different periods, it is easy to see that the variations in their composition are nearly of the same order of magnitude. The importance of antimony and manganese in the formation of colourless and near-colourless glass has been particularly stressed.

The monograph has also dealt with the techniques of glass manufacture, including furnaces, kilns, tools, etc. used in different countries and at different periods to turn out a variety of products.

Insofar as ancient India is concerned, the authors have collected evidences from literary sources apart from the archaeological. It is interesting to note how the descriptions of glass products find place in the epics and in medical treatises. Medicines keep better in glass containers and hence their frequent mention. Because of the sharp edges which broken glass pieces possess, there was mention of glass as a

substitute for metallic surgical tools. There are also many references in literary works to jewels made out of glass materials.

By comparison, archaeological evidences are more numerous, and the monograph deals with them in great detail, citing observations from almost all the excavations (a map is provided to show the locations) about which adequate information is available. It appears from the datings of the excavated locations that glass and glass-making were known in India as early as the chalcolithic period. However, the majority of the finds belong to beads and bangles, the shapes and colours of which necessarily vary considerably. There were also some bowls, containers, rings and rods of glass.

The authors have taken great pains to summarize the information in tabular forms mentioning the various shapes of glass products and their colours, according to the excavated sites in a chronological order. This has enhanced the quality of presentation of the massive data compiled by them. It was observed that there was absence of variety and a lack of quality in Indian glass. One reason seems to be the nonavailability of furnaces capable of producting higher temperatures. Nothing better than what were then manufactured would have been possible in the absence of high temperature furnaces.

The measurements of specific gravity of samples of ancient Indian glass do not show much variation from the data on similar samples from other cultural areas. The compositional data show a general similarity in the use of constituents, but with widely varying proportions. These points have been brought out in detail by the authors in respect of each of the constituents, as well as the raw materials and colouring agents used.

Glass products were established as articles of trade in ancient times among the trading communities of many countries. India used to import a considerable volume of glass products in this way, as is shown by the presence of these products in many of the archaeological excavations.

A very valuable component of the monograph is a laboriously researched bibliography running into more than two hundred entries. The monograph, I believe, has undoubtedly added to our knowledge of ancient glass with particular reference to India, and fulfils a genuine need of the researchers in the field of history of science and technology.

S. K. Mukherjee

Jodhpur Park
Calcutta
10 June 1985

PREFACE

Ancient glass objects, until fairly recently, were valued primarily as objects of art. Interest in the technology of glass-making had to await the development of modern physico-chemical techniques for quantitative analyses of glass objects and determination of their various properties. Although the broad composition of this fourth state of matter had been known for a long time, the temperature at which glass used to be made, the nature of furnaces employed for the purpose, the international use of colouring or decolorizing agents, the selection of raw materials, methods of making glass objects by the core, cane or blowing techniques and various other aspects of technology could only be understood as modern methods of analysis were applied to the study of ancient glass.

The chemical analysis of ancient glass, it is true, goes back to the end of the eighteenth century, and a few samples were analyzed by enthusiastic analysts during the last century, but no systematic analysis could be attempted before the endeavours of Bernhard Neumann and his associates, in the twenties and thirties of the present century. These studies contributed to a better understanding of the technological processes involved in the making of Egyptian and Mesopotamian glass of the second millenniun B.C., Hellenistic Egypt of 1st to 2nd century A.D., Roman glass of the Rhineprovince and so on. Shortly before World War II, Patrick Ritchie and Marie Farnsworth conducted a series of spectrographic analyses of Far Eastern and Eygptian glass objects. After World War II, the development of new and more sophisticated methods of analysis, such as flame photometry, colorometry, electron-beam probe, x-ray diffractometry, infrared spectrometry, greatly facilitated the scientific study of glass. For the first time it became possible to distinguish patterns and recognize compositional categories in ancient glass.

In India the scientific study of glass began with the establishment in 1917 of the Chemical Branch of the Archaeological Survey of India. The task of conducting pioneering studies of ancient Indian glass samples naturally fell to the archaeological chemist Sana Ullah, whose chemical analyses of glass from Taxila, Nalanda, Kurukshetra, Rairh, and Udaigiri immediately attracted the attention of ancient glass specialists all over the world. After the war the scientific study of glass no longer remained confined to the laboratories of the archaeological chemist, but attracted the interest of young analysts in a number of university laboratories in and outside India.

These developments clearly necessitated a fresh study of the progress of our understanding of the technology of ancient glass with special reference to India. The present monograph was planned by the History of Science Unit for the Ancient Period set up in Calcutta by the National Commission for the Compilation of History of Sciences in India under the supervision of one of us (S.N.S.), with which the other author (M.C.) was then associated as a Research Scholar. A detailed review of modern scientific studies of ancient glass from different culture areas has been at-

tempted to emphasize the need for similar studies on Indian glass samples. A suggestion was made at one stage to arrange for thorough physico-chemical analyses by modern techniques of a number of glass samples not yet subjected to such analyses, but this we were unable to do as we were not analysts ourselves. We, however, hope that laboratories and institutes well-equipped for carrying out physico-chemical analyses of ancient glass samples will be interested in this kind of work and will come forward with well-defined analytical programmes.

In the preparation of this monograph we received considerable help from the Central Glass and Ceramics Research Institute, the Geological Survey of India, the Archaeological Survey of India, the National Library and the Asiatic Society, for which we express our thanks to each of these institutions. Our thanks are due to Shrimati Sandhya Mitra for preparing the index. We further express our grateful thanks to the Academy for providing a Senior Research Fellowship to one of us (M.C.) and contingent grants to meet the expenses of the project.

Calcutta
6 May, 1985

S. N. Sen
Mamata Chaudhuri

CONTENTS

CHAPTER I

ANCIENT GLASS—HISTORICAL BACKGROUND, GENERAL CHARACTERISTICS, PROPERTIES, COMPOSITIONS, MATERIALS AND PROCESSES

Nature of Glass

Glass has been known to man for over 3,500 years. Until the middle of the last century it has been produced by more or less the same techniques. Although these techniques have undergone improvements from time to time and are better understood today, some ancient glasses are difficult to duplicate even today. This may appear to point to a refined technology of glass-making in ancient times,—and it was no doubt the case in certain civilizations, but this is primarily due to the peculiarity of the material itself which we call glass.

The fundamental peculiarity of glass is that it does not fit in with any of the three classical states of matter. Superficially, it is a hard, rigid, brittle, non-crystalline and highly viscous substance which may be transparent, translucent or opaque, and also variously and brilliantly coloured. Glass has no sharp melting point; it softens and becomes mobile around 1000°C. When molten glass is cooled relatively quickly below this temperature, it does not crystallize into a solid state as most substances do, but congeals into a hard, highly viscous, amorphous state. On account of this peculiarity, glass is often described as a supercooled liquid.

Nevertheless, under certain circumstances glass does crystallize. If it is cooled too rapidly after strong heating, the whole or part of it may fall into a crystalline state. Glass kept on for a considerable length of time or subjected to external forces such as sudden impact, etching etc. may also suffer a similar change. Such crystallization of glass is called 'devitrification'.

Chemically, glass is obtained by melting a mixture of silica or sand (about 65–74%), soda (about 14–18%) and lime (about 7–9%), in which some other metallic oxides like magnesia (MgO), alumina (Al_2O_3) may be present in small but varying quantities. This is the composition of a typical modern soda-lime-silica glass. Here, silica, the acidic oxide, may be regarded as the solvent in which are dissolved as solutes basic metallic oxides of the type R_2O (chiefly soda and potash), RO (chiefly oxides of calcium, barium, magnesium and zinc) and R_2O_3 represented by the oxides of aluminium and iron. Other oxides of metals such as cobalt, nickel, chromium, tin, copper, lead, uranium etc. may be present as colouring agents, and manganese, antimony and selenium oxides serve as decolorizing components. A number of other acidic oxides, e.g. boric oxide, phosphoric anhydride and arsenious anhydride, may also partially or wholly replace silica in the making of glass. In practice, every glass works uses its own particular formula; the files of Corning Glass Works, for example, contain some 75,000 compositions for glass. What is more important in understanding

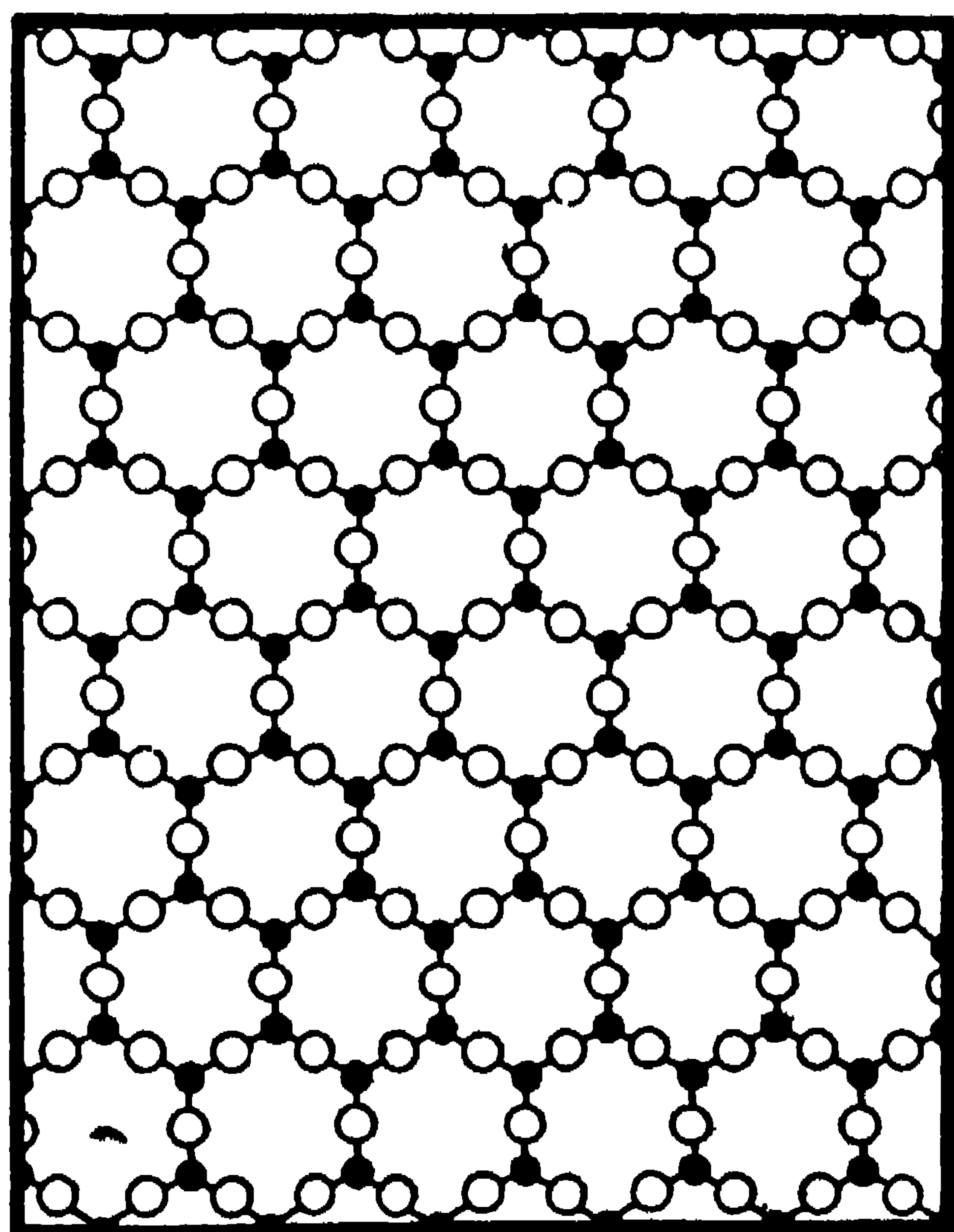
glass as a class of substance is therefore not its particular chemical composition but its physical characteristics, more particularly, the internal arrangements of atoms of the various elements participating in the building up of the glassy state.

In fact, this glassy state in which materials are in a position to exhibit the mechanical rigidity of crystals on the one hand and the disordered and random structure of liquids on the other hand is sometimes called the fourth state of matter. It is possible to have a better insight into the glassy state through x-ray studies and other physical measurements. Each of the three major constituents of a typical soda-lime-silica glass, e.g. quartz (SiO_2), sodium carbonate (Na_2CO_3), and calcium oxide (CaO) has a crystalline structure due to ordered arrangement of their atoms. A simplified two-dimensional representation of SiO_2 crystals in which silicon atoms are represented by solid dots and oxygen atoms by open atoms is shown in Fig. 1(a)[a] The atoms are held in position in such a lattice arrangement by powerful chemical bonds. When a quartz crystal is heated to about 1500°C, the absorbed thermal energy throws the atoms into violent vibratory motions, disrupts the chemical bonds between them and brings about a chaos and disorder in the regular arrangement of atoms. This is the molten or liquid state characterized by a disordered arrangement of atoms. If the molten mass is allowed to cool relatively quickly, the silicon and oxygen atoms may not find time to revert to their previous ordered positions in the ordered lattice and may continue to have a disordered structure as in the liquid. But with the loss of thermal energy and consequent subsidence of vibrational and other motions, chemical forces will become strong enough to give the mass the rigidity of a crystalline solid. The disorderly atomic dispositions of glassy state of fused silica is shown in Fig. 1(b).

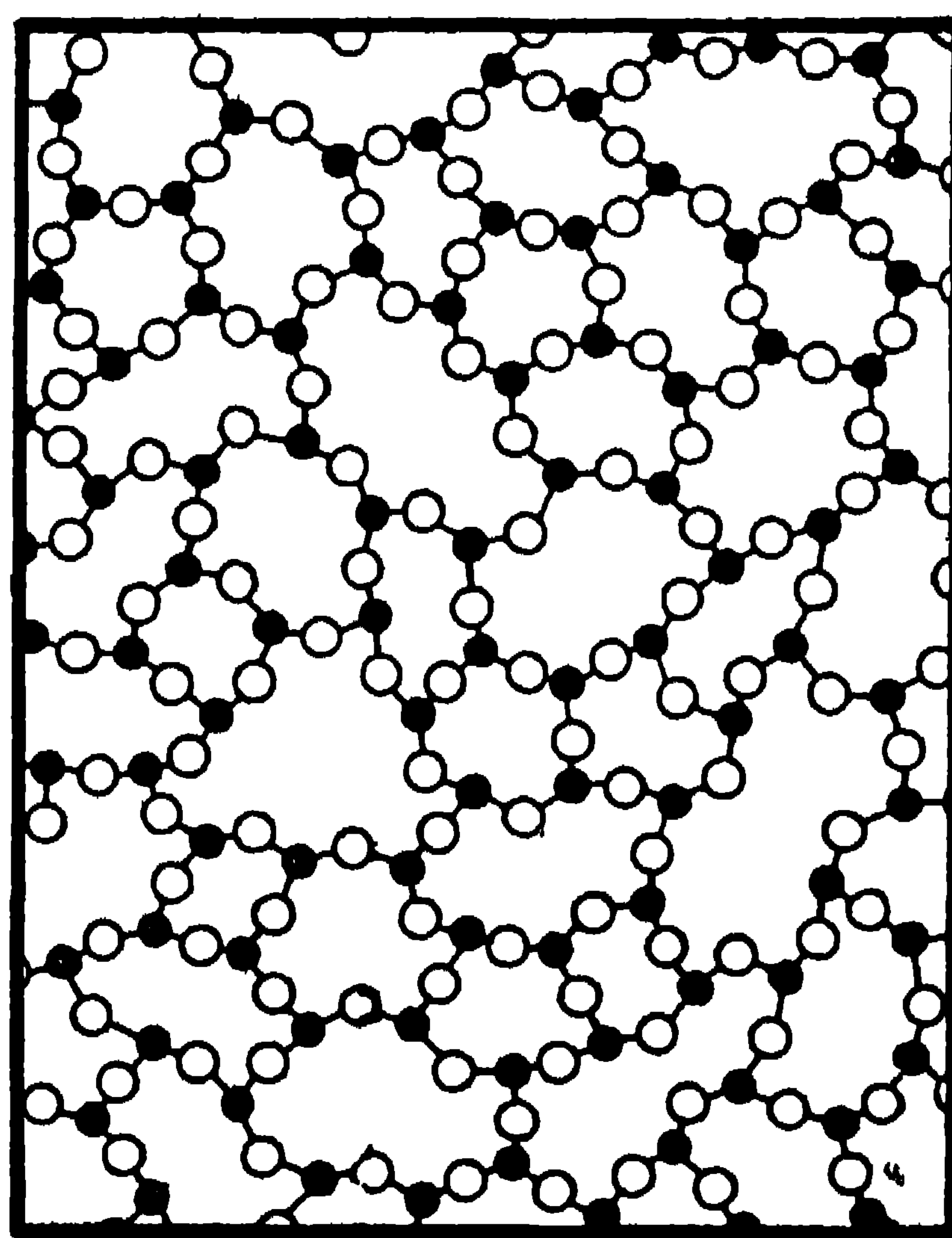
Similar ordered dispositions of atoms in a two-dimensional crystal lattice of sodium disilicate ($Na_2Si_2O_5$) and their disordered arrangement after the same is fused and turned into a 'glassy state' are shown in Figs. 2 (a) and (b). The cross-hatched circles stand for sodium atoms. The way in which the regular arrangements of sodium atoms in between oxygen atoms in crystalline state is disrupted and the silicon-oxygen linking patterns are distorted and broken down, presenting an over-all disorderliness, is clearly shown. A specimen of an ancient Roman glass (3rd century A.D.) contains, besides the major constituents silica (64%), soda (18.0%), and lime (6.8%), minor constituents like potash (0.5%), magnesia (0.8%), alumina (2.0%), iron oxide (0.5%), manganese dioxide (trace) and titanium oxide (trace), and colouring agents like copper oxide (0.5%), and antimony oxide (0.87%). The disordered two-dimensional arrangement of atoms of these various constituents in such an ancient glass, as reconstructed by Brill to illustrate the point, is shown in Fig. 3.

We have already referred to the high viscosity of glass, a property of fluids, which also gives us an idea as to the glassy state of matter. This is a kind of force which is called into play between fluid layers in motion with a velocity gradient and is measurable in a unit called 'Poise'. For glasses at room temperature, this value ranges between 10^{19} to 10^{22} Poises, whereas for water, SAE-30 motor oil and molasses it is of the order of 0.01, 1.0 and 10 Poises respectively. Its temperature variation in the case of glass is more remarkable in that it drops gradually from its high value of

[a] Brill (3), 127–38.

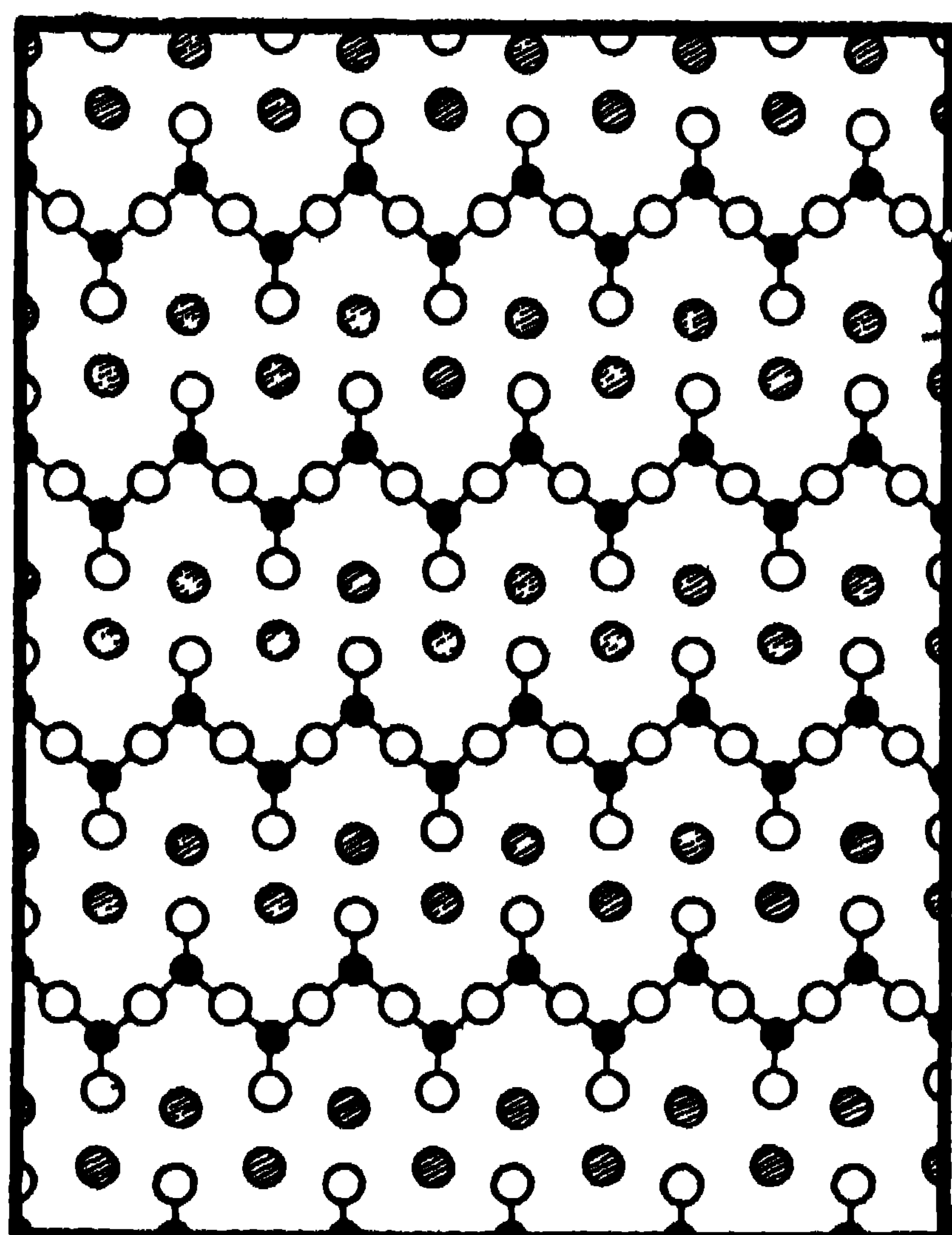


(a) Quartz crystal

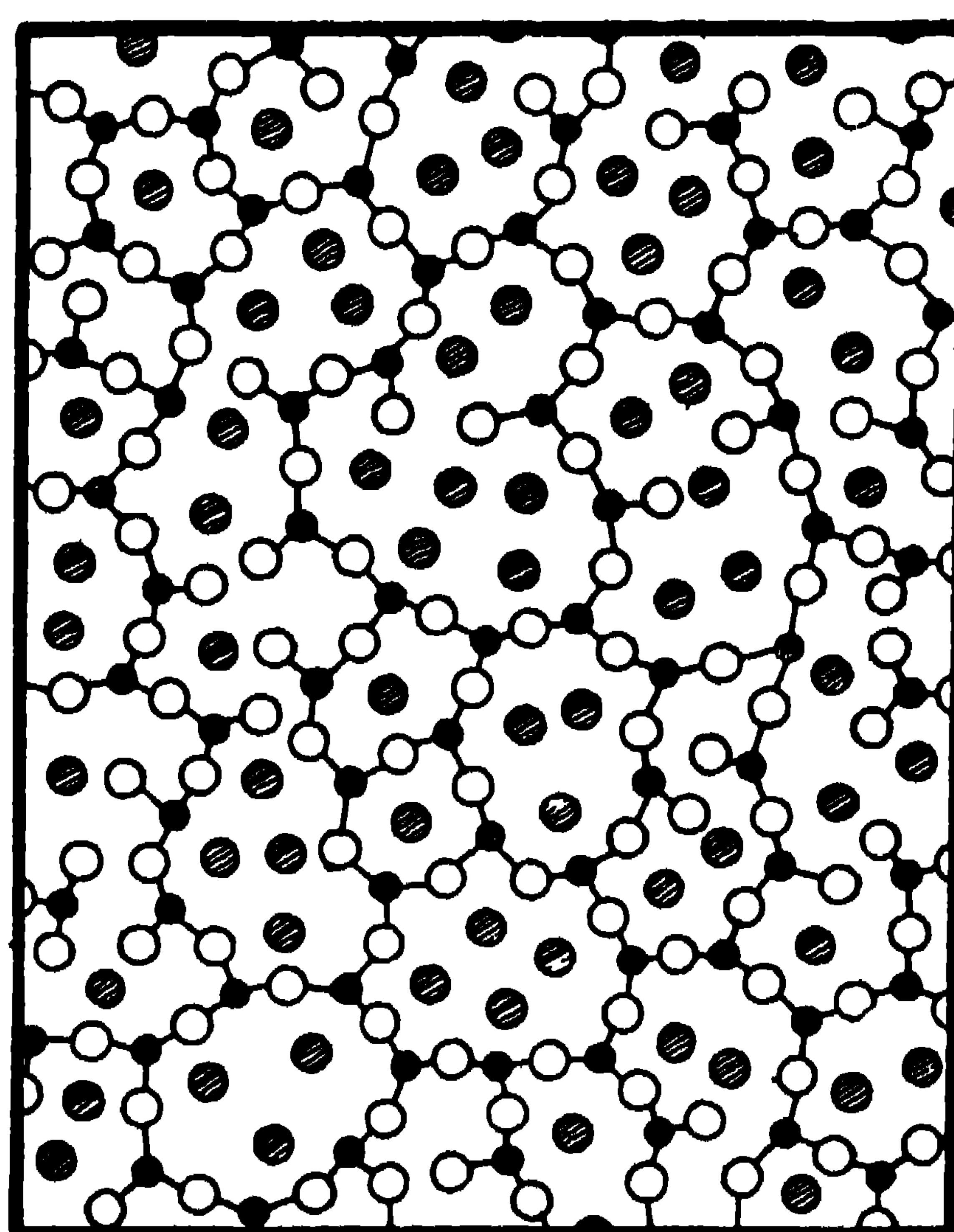


(b) Fused silica glass

Fig. 1—A simplified two-dimensional representation of SiO_2 crystals.



(a) Sodium disilicate crystal



(b) Soda-Silica glass

Fig. 2—Two-dimensional crystal lattice of sodium disilicate in ordered and disordered state.

10^{19} Poises to about 10^7 Poises at the softening point (between 600–700°C) and to about 10^{3-4} Poises at still higher temperatures at which glasses are fluid enough to be moulded or blown. Temperature ranges over which softening or fluidity takes

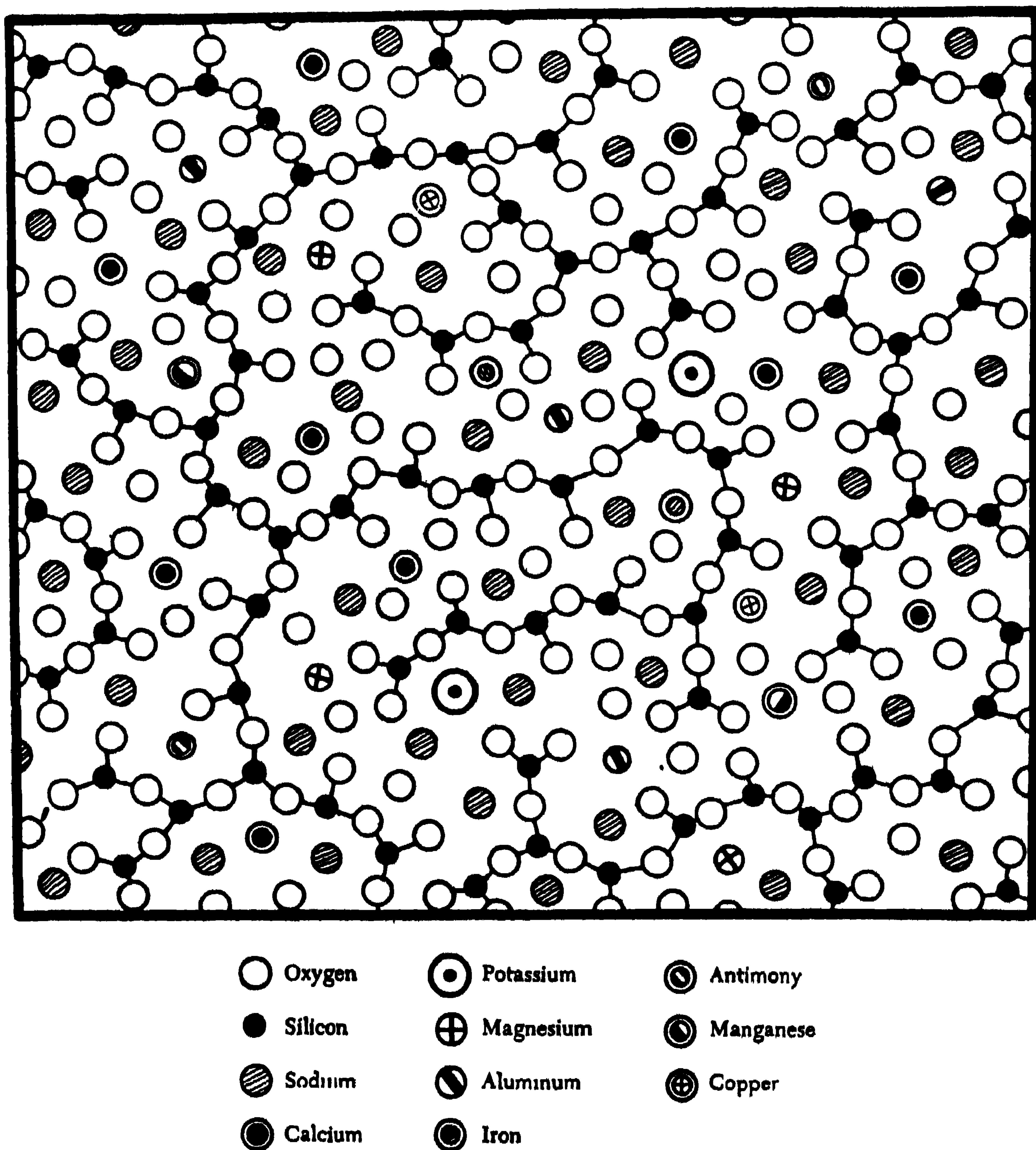


Fig. 3—Disordered two-dimensional arrangement of atoms of various constituents in a typical Roman glass (after Brill).

place vary widely and depend on the particular composition of glass. It is on account of such continuous change of viscosity with temperature, unlike crystalline substances, that even when its viscosity is as high as 10^{19-20} Poises it is preferable to describe glasses as highly viscous supercooled liquids.

Glazes and Faience

In dealing with ancient glass objects, it is necessary to differentiate glass from two other materials, viz. glazes and faience which have some common ingredients and

present some identical superficial effects, but which are not true glasses. These two materials also deserve more than a passing notice in view of their probable connections with the origin of glass.

A glaze is a vitreous substance which is applied in thin layers to another substance acting as the core material. In antiquity, stone, quartz and steatite frequently served as core materials. The usual practice was to apply a vitreous glaze in powdered form on the surface of the core body, moisten it with water and then fire the whole thing in a furnace. The constituents of alkali glaze, like glass, are silica, alkali oxides, lime, iron oxide and alumina and a small amount of copper oxide as colouring agent. The percentage of silica in glazes is usually very high, being 86–88 per cent, the amount of alkali varying from 3.7 to 5.5 per cent and that of lime from 1.40 to 1.80 per cent. We have also evidence of application of lead glaze on pottery materials in Mesopotamia which has yielded cuneiform texts containing formula for a lead glaze. Such lead glaze was, however, a rarity in antiquity and attained some measure of popularity during late Hellenistic, Roman and Byzantine times.

The history of glaze is uncertain. One of the many suggestions put forward is the accidental development of a glaze on the surface of a malachite grinding stone, when heated in the presence of some alkali.[a] It is not possible to say where such accidental development first took place, but there is ample evidence to show that in the third and the second millennium B.C. glazing had become an established art in Egypt, Mesopotamia, Syria, Crete and India. In Egypt, green glazes appear on Badarian pottery, steatite beads, seals etc. Although the green glaze was the commonest of all coloured glazes, blue and other colours were not rare. The earliest finds of glazed objects from Mesopotamia refer to the Jemdet Nasr Period (*c.* 3000 B.C.) where also the art of glazing was confined mainly to beads and seals. As already mentioned, one important feature is the appearance of lead glaze on early Mesopotamian pottery. Lead glaze is more glassy and smooth, but peels off readily due to its poor adhering qualities. In the Indian subcontinent, glazed spindle whorls on pottery base, vitreous paste, vitreous slabs of carnelean blue colours and glazed beads have turned up at Mohenjo-daro and Harappa.[b] The chemical composition of one such vitreous paste was found as: silica—85.90%, ferric oxide and alumina—6.74; lime—1.73; magnesia—0.38; alkalies—3.70; copper oxide—0.46.

Another glass-like material but not exactly glass is faience which appeared several centuries before the development of true glass. Finely powdered quartz moistened with a solution of sodium carbonate or natron of ancient Egypt in a clay mould and then fired produces faience. It is important to bear in mind that faience always used to be moulded in the powdered form held in shape by the adhesive action of moist sodium carbonate intrusions before being fired into a stable form. The result of such firing is a smooth glassy surface overlying a body of crystalline grains of quartz rather loosely held together. Chemical analyses show that faience body consists of largely silica crystals with a small admixture of soda and a few other impurities. Such analyses on a large number of Egyptian objects reveal composition of 95% of silica, the remaining 5% being taken care of in equal proportions by alumina, lime,

[a] Harden (4), 315. [b] Marshall, John, 469.

magnesia and iron oxide.[a] X-ray studies confirm that structures of silica crystals conform to those of α-quartz, indicating that the temperature of the furnace where faience was made did not exceed 870°C as otherwise hexagonal crystals of tridymite would have been detected.[b]

ORIGIN OF GLASS

The possibility of such early experiments with glazes and faience ultimately leading to the glass-making technique need not be doubted. Forbes is more or less definite that glass was the outcome of glaze.[c] In glaze and faience, the amount of glass formed is very little. In the case of glazes, the occasional peeling off was a nuisance and must have irritated the artisans in the glaze-making jobs. In the case of faience, porous sand grains constituted the bulk of the material beneath the thin glassy layer. In such circumstances, wilful or accidental increase in the proportion of alkali (natron) and milk of lime used in faience as binder and prolonged firing could have surely produced a large mass of glass or glass paste. The existence of a kind of glassy faience which is a transition state between faience and true glass lends further strength to the glaze or faience-to-glass hypothesis. Moreover, that the motive of all these vitreous materials—faience, glaze and glass—was to produce imitations of precious or semi-precious stones and that this motive remained the same for several centuries even after glass-making became an established art, should not be overlooked. Curiously enough, despite the familiarity of the Egyptians with the art of making faience and glazes for about 1000 years, glass was not made there by one of those plausible accidents before 1500 B.C., and it is still an unsolved question whether glass was at all made there first or whether the technique was not borrowed from elsewhere and then developed and perfected.

We have already noticed the possibility of an accidental development of glaze on a malachite grinding stone heated in the presence of some alkali. Some scholars are now inclined to believe in the theory of glass-making having originated in the ancient metallurgical operations involved in the smelting of copper and lead.[d] In ancient Egypt, azurite was mined for copper and pigment of the artificial blue frit and malachite for glazes, mural paintings, eye paint but mainly for copper smelting. Examination of pottery crucibles used for the smelting of copper ores reveals vitrified silicious slags. Experience of such vitrification coupled with the fact that early glazes and glasses used to be coloured blue with the intentional addition of copper oxides gives further strength to such a theory. Moreover, in the pottery kilns used in early copper smelting operations, a temperature of over 1000°C could have been reached without difficulty, a temperature also quite favourable for the making of glass.

Brill has drawn attention to another interesting compound, a crystalline copper calcium silicate ($CuO.CaO.4SiO_2$), the famous Egyptian blue, which was a chemical cousin of glass. It is a porous material like faience, has a small glassy matrix, much more compact and durable. This Egyptian blue found its use mainly as a pigment in wall paintings and occasionally in jewellery.

[a] Lucas (2), 184–92. [b] Brill (4), 123. [c] Forbes, 113. [d] Brill (4), 120.

Elder Pliny's account of the accidental discovery of glass on the sandy coast of Phoenicia by some merchants in the course of an ordinary cooking operation on blocks of natron, is now discounted. Pliny's story was propagated in subsequent centuries by influential scholars and writers like Tacitus and Isidore. Phoenician sands, particularly those of Belus mentioned by Pliny and Strabo, provided by far the best silica that could be obtained anywhere in antiquity, and, in the presence of sufficient quantity of sodium carbonate, it was not impossible to obtain a glassy mass at the temperature of the hearth used for such cooking. But we now know for certain that the reputation enjoyed by Phoenicia in antiquity as a centre for excellent glass-making belonged to a later date; several centuries before glass came to be manufactured in this coastal strip along the Mediterranean, this fourth state of matter had been made in quantity in Egypt and Assyria to be shaped into different kinds of objects and vessels of great beauty fit to be used and admired in royal houses throughout the ancient Near East.

Origin of Glass Vessels: Egypt vs. Mesopotamia

Glass-making techniques are equally ancient in both Egypt and Mesopotamia, although the history of their development has followed different patterns. From the sheer wealth of glass objects unearthed in Egypt from predynastic graves at Qau, Abydos and elsewhere, more particularly from the tomb chambers of the kings of the New Empire (1580–1090 B.C.) and from the paucity of such finds in Mesopotamia, scholars in the beginning of the century generally concluded that glass was an Egyptian invention. Anton Kisa believed that in the second millennium B.C. only Egypt had the distinction of possessing a glass industry and anything like it was unknown in Mesopotamia, or for that matter, anywhere outside Egypt.[a] The Assyriologists, however, never quite agreed with this view. Recent studies indicate that the Mesopotamian collections, although small in number, are as old as some of their Egyptian counterparts, that the rarity of ancient glass objects in this humid region is due to their disappearance by the rapid weathering processes, and that Mesopotamia appears to have as good a claim as Egypt in the invention of glass, possibly more so in the invention of techniques for the making of glass vessels.

As to earliest glass objects, beads of various colours, obviously made in imitation of precious or semi-precious stones, have turned up in predynastic graves at Nagada (4000–3500 B.C.), Abydos (3500–3250 B.C.), Qau (2600–2500 B.C.), Deir el-Bahri (2400–2200 B.C.) and Dahshur (2100 B.C.).[b] Many of the beads previously claimed to be of glass on imperfect examination have subsequently been confirmed as faience, but a good many of them have also proved to be of genuine glass.[c] Objects other than beads include the 11th dynasty blue glass lion's head (2100 B.C.) found by Drovetti at Thebes and a mosaic glass rod with the cartouche of Amenemhat III (2000 B.C.). In Mesopotamia, cemeteries of Ur III (2100 B.C.), Tell Asmar (2700–2500 B.C.), Abu Shahrein (formerly Eridu) (2700–2600 B.C.) in Iraq have yielded glass beads and pieces of well-melted glass. A small pale green glass rod from Asmar

[a] Kisa, 102 ff; see also Beck (3), 7–21. [b] Beck (3), 7–21. [c] Lucas (2), 39–44.

measuring 1.33″ long and 0.45″ diameter is a specimen of very pure glass ($\mu = 1.515$ and sp. gr. = 2.463) with few air bubbles.

Glass vessels do not appear either in Egypt or in Mesopotamia before *c.* 1500 B.C. In Egypt where the foundations of the 18th Dynasty and of the New Kingdom were laid in 1583 B.C. and an era of unprecedented political vigour and industrial activity was ushered in, we witness the advent of a new dimension in her already ancient glass industry producing for the first time glass vessels by the core and the cane code techniques. At least 50 complete specimens of glass vessels and numerous fragments that formed parts of about 250 vessels have so far been found. At the beginning of the 18th Dynasty, these objects were still rare, for from the tomb of Thutmose I (1525–1495 B.C.) only two glass fragments, one of them forming part of the rounded base of a bottle, have been found. Piriform bottles with flaring rim, rounded base, and designs in multi-thread festoons and feather-like zig-zag patterns have come from the tomb of Maherpra (first half of the 15th century B.C.) and Amenhotep II (1439–1406 B.C.). The tomb of Thutmose III (1490–1436 B.C.) has yielded three complete vessels bearing this king's cartouche, two in turquoise blue glass and one in bluish glass, and a number of fragments of a turquoise blue bottle, decorated with yellow and black threads. The reign of Amenhotep II witnessed a vigorous glass industry as is evidenced by the discovery in the tomb chambers of this king in the Valley of the Kings of about 3000 glass fragments, being parts of several vessels.

The Egyptian vessels were small flasks and bottles used as containers for cosmetics and perfumes for which Egypt was famous and were in great demand in antiquity. Such flasks and bottles of Egyptian origin have turned up in Lachish, Tell el-Ajjul, Gezer, Beth Shemesh, Megiddo, Ugarit and other archaeological sites in Palestine and Syria.[a] With the end of the 18th Dynasty, the glass industry declined in Egypt and little is heard of it from the 10th century B.C. until its revival in the 7th or the 6th century B.C.

The Mesopotamian glass vessels have come from archaeological sites in Nuzu (Yorgan Tepe) near Kirkuk in modern Iraq, Assur, Ur, Dur Kurigalzu (Kassite palace), 20 miles to the west of Baghdad, Babylon and Alalakh (modern Atchana) in Antioch. Core-formed glass vessels from Nuzu comprise a straight-sided goblet, a small open vase, a small bottle with a plain surface and another small bottle with fluted surface. Belonging to the period of Saushshatar, King of Mittani (first half of the 15th century B.C.), Nuzu glass wares bear forms and decorations (festoons, feather patterns, zig-zags, meanders etc.) charactersitic of local pottery and ceramic types. The Tomb 37 and Grave 133 below the Nabu Temple but at the height of the ancient Temple of Tukulti Ninurta I at Assur have yielded a number of glass fragments and piriform bottles, now preserved in the Staatliche Museum, Berlin. All piriform bottles have more or less flaring thickened rims with pointed bases in some cases and knobbed ones in others. The designs include horizontal bands, rows of blobs, fluted feathered patterns, festoons, meanders etc. One such bottle from Tomb 37 was made of green or turquoise blue glass, with patterns in festoons and meanders and bore some analogy with the Maherpra bottle. Other finds include tripodal beaker made of brown

[a] Barag, 22, 26.

glass and glass pins. According to Haller who described these objects, the date of the Tomb may be placed in the middle of the second millennium B.C. and that of the Grave in the middle Assyrian period (1500–1100 B.C.).[a]

Other glass objects of the period include inlaid glass plaques from the Kassite Palace at Dur Kurigalzu (*c.* 14th century B.C.), a piriform bottle from the Kassite level at Ur (1300 B.C.) bearing resemblance to types found at Nuzu and Assur, and fragments of glass vessels from the various levels (end of the 16th century to 14th century B.C.) with close Mesopotamian affinities.

After a careful comparison of the characteristics of Egyptian and Mesopotamian glass in the second millennium B.C., Berag has expressed the view that, although glass appeared more or less simultaneously around 1500 B.C. and chronologically one cannot be placed before the other, Mesopotamia might be the probable place of invention for the following reasons.[b] Mesopotamian glass exhibits a certain superiority over the Egyptian. Egyptian glass was scarce at the beginning of the reign of Amenhotep II, but became fully established in his time, indicating the time of naturalization of the industry in Egypt. The presence of cobalt compounds in glass indicates the direction of transmission from Iran via Mesopotamia to Egypt. To this should be added the discovery of a cuneiform tablet of the 17th century B.C. from Tell Umar and several tablets from the library of Ashurbanipal, all dealing with the preparation of glaze or glass.

In the 8th and the 7th century B.C. another outburst of glass industry is recorded in the Near East in which Phoenicia, Palestine and Syria and later on Alexandria, the new capital of hellenistic Egypt, played the most prominent part. Although various techniques employed in the glass industry, e.g. core technique, cane code, mould-pressing, cold-cutting etc., continued to be practised as before, some of them underwent improvements, and new techniques of making gold glass, mould-cast glass, 'millefiori' wares etc. were developed, resulting in better and more attractive glass wares. Harden calls the beginning of this period 'the era of sea-green cold-cut glasses'.[c] A piece of alabastron bearing the name of Sargon II (722–705 B.C.) in cuneiform script is a typical example of glass of this period.

In Phoenicia where the beginnings of a glass industry are obscure, Sidon sprang to a position of pre-eminence and soon rivalled Alexandria and other Egyptian centres in the production of excellent glass. The vigour of the Achaemenian empire possibly had something to do not only with the vitalization of the glass industry in its old centres in Mesopotamia and Syria, but also with the diffusion of the ancient glass-making techniques throughout the Persian empire. The Sidonian glass workers included both Syrian and Jewish families who practised the craft on hereditary lines. After the discovery of glass-blowing in the first century B.C.—and it was without doubt made either in Syria or in Phoenicia, these Syrian and Jewish glass workers attained still greater prominence and helped in the propagation of their craft throughout the Roman world—in Italy, Spain, Gaul and the Rhineland. The foundation of the glass industry in Byzantium in the 7th century A.D. was laid by the Jewish technicians.

[a] Haller, 65. [b] Barag, 25. [c] Harden (4), 321.

In Egypt, as has already been mentioned, hellenism helped in the revival of the ancient Egyptian art of glass-making, and Alexandria led the way by producing some of the finest wares of the time, e.g. the Megarian bowls, the Canosa bowls, the gilt-sandwich glass and finally the much admired *millefiori* or *murrine* wares. Despite Egypt's long tradition in glass-making and the excellence of her artistic skills on glass wares, glass blowing was not discovered in the Nile valley or delta, and after it was done, the introduction of it there was delayed by the traditional conservatism of her craftsmen.

Glass after Glass Blowing: Development in Roman Times

There is now a general consensus that glass blowing was discovered some time during the first century B.C. either in Syria or in Palestine. Blown glass objects do not appear in any of the Ptolemaic levels in Syria, Egypt or Cyprus but appear in plenty in Augustan levels throughout the Roman world.[a] The introduction of the new technique revolutionized the glass industry, changed the whole character of glass wares, rendered obsolete the long familiar clumsy thick-walled vessels and, through mass production and consequent cheapening of price, helped glass to become a common household commodity. A middle-class Roman household usually had a fair storage of glass containers, drank from glass vessels, looked through crude window panes and made presents of souvenir glass cups with designs of favourite gladiators. That by the second or the third century A.D. glass wares were common features on the tables of ordinary Egyptian people has been confirmed by the discovery in the cellars of a house at Karanis of several pieces of oval glass dishes, bowls, conical lamps, drinking cups, jars and flasks.[b]

The discovery probably arose in connection with the practice of blowing glass melt on to a mould in the mould-pressing technique of making glass wares. That the adhering melt instead of being transferred to a mould can itself be blown to shape appears to be a logical step to have been taken by the Syrian or Palestinian glass blowers who had been working with the mould-pressing technique. According to Eisen, the invention took place at the hands of glass workers skilled in making mosaic glass.[c]

Unlike the Greeks who had remained satisfied with the imported glass wares from Egypt and Asia, the Romans took an active interest in learning, promoting and spreading the glass industry. A glass industry probably flourished at Aquileia at the head of the Adriatic before the Christian era, and many early Romans were doubtless familiar with the Egyptian products. But things changed fairly rapidly with the annexation of Egypt in 30 B.C. when glass workers first from Alexandria and then from Syria and Phoenicia moved to Italy to set up their houses to capture the lucrative Roman market. Pliny, in his *Natural History*, 36, records that Alexandrian craftsmen set up glass factories at the mouth of Volturnus and near the Porta Capena in the beginning

[a] Forbes, 148.

[b] Harden (2), 'Roman Glass from Karanis', *University of Michigan Humanistic Series*, **41**, Ann Arbor, 1936. [c] Eisen, 134–43.

of the first century A.D. and the Syrian craftsmen started their operations not long after in the imperial city of Rome itself. Glass vessels of the Roman period disclose the names of master Syrian craftsmen like Ennion, Ariston, Artas, Eirenaios, Nikon, Jason, Tryphon and several others.[a] Ennion, the Sidonian, went to Italy to set up his factory there, and his wares were so popular that glass vessels with his name stamped on them have been found from several places of the empire.

Once in Europe, these Syrian and Jewish glass blowers did not long remain confined to Italy. A good number of them crossed the Alps and migrated to Gaul, Spain and the Rhineland to lay the foundations of glass industry there. The ancient glass works at Colchester, Warrington and Norwich in Britain must have arisen by contact with these West European centres. Nearer home, the Syrian and Jewish craftsmen steadily moved to Mesopotamia, Cyprus, Greece and Southern Russia to spread their techniques. Harden had made the important point that from very early times the glass workers had developed a peculiarly migratory habit by virtue of which they restlessly 'moved from factory to factory, spreading their wares, but not their knowledge.'[b] Thus, during Roman times, in spite of their wide geographical spread, the Syrian and the Alexandrian glass technicians, no doubt reinforced from time to tme from their home centres, continued to produce glass wares bearing their own characteristics in technical details of manufacture, shape and patterns and artistic designs. If the glass industry freely spread in this way within the bounds of the Roman empire, glass wares of the period as popular articles of trade travelled farther beyond, leaving to this day their traces in such far-flung areas as Begram (ancient *Kapisa*) in Afganistan, India, South-East Asia, Central Asia, China, Korea, the deserts of Sahara, the highlands of Scotland, northern Germany and Scandinavia.

In spite of the practice of salvaging and remelting broken glass by the Roman glass blowers, enough specimens of Roman glass from different parts of the empire have survived and now constitute the precious collections of several national museums. The well-known Berlin Antiquarium Collection had before World War II some 2,800 items of ancient glass, all of which perished in a fire in a bunker in Friedrichshain. Fortunately, some 130 examples stored outside Berlin escaped the catastrophe and are now in the West Berlin Museum. Specimens of Roman glass in the collection, recently noticed by Greifenhagen,[c] include a shallow *millefiori* bowl (early Roman empire), distinguished by yellow-red tulips over a general pattern of yellow stellate flowers; a mould-blown beaker of transparent green glass (Syria, 1st century A.D.), an *alabastron* with green, blue, yellowish-grey and light-grey wavy bands with 'shattered' gold foil (Alexandrian, 1st century A.D.); a mould-blown lenticular flask of greenish transparent glass (Syria, 1st–2nd century A.D.); a head flask of blue transparent glass, also mould-blown (Eastern Mediterranean, 3rd–4th century A.D.); a spherical vessel and a bottle made of opaque red and white feather patterns on deep dark blue glass matrix (late classical period or early Islamic).

Several examples of Roman mould-blown glass wares, now at the Yale University, have been described by Jane Hayward.[d] The collection has one mould-blown bowl by Ennion, one of 21 signed examples by this early Sidonian master (Syria, 1st century

[a] Forbes, 151. [b] Harden (4), 320. [c] Greifenhagen, 61–66. [d] Hayward, 49–60.

A.D.); it was made of transparent pale bluish green glass blown in a four piece mould with decorations. A beaker, bearing the name of its maker 'Jason' (Syria, 1st century A.D.) and the sixth 'Jason' example so far known, is made of pale bluish green glass blown in a tripartite mould and is of uniform shape and size. Other examples include a transparent greenish blue cup (1st century A.D.); a transparent greenish amber pitcher (Syria, 1st or 2nd century A.D.); a colourless glass flask with various designs in floral motifs, an urn and a pair of scrappers (Syria, 1st or 2nd century A.D.). Several beakers with bacchanalian scenes and figures and reliefs of Roman deities like Neptune and Jupiter, flasks with scenes from the Argonaut legend and a jar with masks, mostly belonging to the period between 1st–2nd century A.D. and some to the 3rd–4th century A.D. and made probably in Syria and Eastern Mediterranean, provide some beautiful and typical examples of Roman glass wares. The colours of these vessels, varying from one another, are greenish-amber, transparent amber with striations of amethyst, transparent green, opaque white and transparent amethyst with buff striations.

Another important find which has recently made quite an impact on the history of ancient glass technology is the giant glass slab, measuring 3.40 m long, 1.95 m wide and 50 cm in average thickness, discovered in Beth She'arim, an ancient Jewish site 12 miles south-east of Haifa, well known for glass-making during Roman times.[a] Weighing 8.8 tons, the slab reminds one of the giant glass slab of 14.5 tons made in this century for the 200-inch reflector at Mt. Palomar and another unsuccessful blank cast weighing 20 tons for that mirror. The exact date of manufacture is still a matter of guess, but it could be at any time between the 4th and the 7th century A.D. Similar large glass slabs have been discovered at Arsuf, some 50 miles of Beth She'arim, dating probably from the late Roman or early Byzantine period. It is known that large glass slabs used to be made at a few centres specializing in such manufacture, to be subsequently broken up into small fragments for distribution to glass workers who in their turn remelted and fashioned them into desired wares. There is also evidence for turning out such solid blocks for making glass floors.

Glass in China, Japan and Korea

Glass-making in the Far East from the sixth to the third century B.C. has been proved by the discovery of glass objects in early graves in Japan, and Korea, and from a number of sites in China.[b] The Ch'in tombs in old Lo-yang (Ch'en Chou), about 13 miles north-east of modern Lo-yang in Western Honan, have yielded a number of glass objects, mainly small pieces of beads of various sizes and shapes, mounted in plaques of bronze. These objects were at first believed to date from the sixth century B.C. on the basis of a date equivalent to 550 B.C. inscribed on one of the bronze bells discovered in these tombs, but Beck and Seligman, on the authority of Prof. Pelliot, placed them in the second half of the third century B.C.[c] The bronze plaques have been inlaid at the centre by convex-shaped glass discs in the 'eye' motif, so designed and arranged as to give the impression of movements—one set of seven in

[a] Brill (7), 88–95. [b] Sarton, *ISIS*, 25, 73–79. [c] Beck and Seligman, 982.

the counter-clockwise direction and the other set of seven in the clockwise.[a] Similar beads have been found in North Honan. Examples of other glass objects include a small cylinder-shaped object of green glass in the Hin-Chen finds (5th or 4th century B.C.). There is no indication of glass vessels being made at this early date in China.

Glass beads of Western origin have turned up in Han Chun graves and in Korea during the Silla period. These beads and other glass objects found by Aurel Stein in Lou-Lan and Niya on the Central Asian trade routes have such similarities with Mediterranean beads of the same period that these have been supposed to be of Western origin, being brought there through a thriving trade in such articles along the old overland silk routes. Likewise, beads of lead glass found in Western Asia might have got there in the same way from China, which had specialized in the making of lead-barium glass as early as the time of Old Lo-yang when such a composition of glass was unknown in the Mediterranean region.[b]

Chemical and spectrographic analyses of glass objects, belonging to the periods of the Chou, the Han and later dynasties, have revealed that barium-lead glass preponderated in the pre-Han and Han period (202 B.C. – 220 A.D.) while soda-lime glass of more or less the same composition as known everywhere in the Near East dominated the Chinese glass houses from the Thang period (618–906 A.D.)[c,d]

Chemical Composition

ANCIENT LITERARY EVIDENCE

Although the best way of ascertaining the composition of ancient glass is by direct chemical analysis by the wet process and by the non-destructive physical methods such as spectrographic, electron-beam probe, x-ray diffraction, etc., a number of cuneiform tablets containing directions for the making of glass and glazes are known. One such tablet from Tell Umar dating from the 17th century B.C., now in the British Museum (No. 120960), contains the recipe for 'santu (red) glass of lead', from which the following, in the translation of Gadd and Campbell,[e] is quoted:

1. To a mina of Zukû-glass (thou shalt add) 10 shekels of lead
2. 15 shekels of copper, half (a) shekel of saltpetre, half (a shekel) of lime
3. thou shalt put (it) down into the kiln (and) shalt take out santu (red) glass of lead
4. To a mina of Zukû-glass (thou shalt add) 1/6 (mina: 10 shekels) of lead
5. 14 (shekels) of copper, 2 shekels of lime, a shekel of saltpetre:
6. Thou shalt put (it) down into the kiln (and) shalt take out Accadian santu (red)-glass
7. (Thou shalt) green the clay and (set) in vinegar and copper thou shalt keep it
8. at the third (day) of thy keeping
9. it will deposit a bloom and thou shalt take (it) out.

[a] White, 148. [b] Forbes, 160; Seligman, 5–20. [c] Beck and Seligman, 982.
[d] Ritchie, 209–20. [e] Gadd and Campbell-Thompson, 87–96.

The directions given above and further on in the text have been applied in making glass and proving thereby the feasibility of the recipe.[a]

Ashurbanipal's library at Nineveh has yielded a number of chemical cuneiform texts, some of which are recipes for practical glass technologists for the making of frit, *Zukû* glass, blue frit (*tersitu*), lapis-blue glass (*uknû*), sapphire glass (*ṣipru*) and others. To make the lapis blue glass, the text directs as follows:[b]

> Thou shalt crush separately
> 10 mana of tersitu (blue frit)
> 10 mana of siṣu-glass
> . . . of alkali, in small pieces, not round lumps
> 2/3 mana of chalk of the sea (shells ?)
> roasted cinnabar (?)
>
> Thou shalt mix them together, collect them into a clean melting pot, and put it down into the cold melting-furnace, and thou shalt put it on a support (of sand ?) between the "eyes" of the furnace, the base of the melting-pot not touching the furnace, thou shalt keep a good smokeless fire burning; and when the fire from the middle of the apertures has driven forth the bubbles (from the batch) and the pot metal glows, thou shalt draw the fire: when the furnace is cold thou shalt take it out and crush it. Thou shalt collect it into a clean melting pot and put it down into the cold takkanu-furnace on a layer of sand. Thou shalt keep a good smokeless fire burning and while the metal is fusing thou shalt not shut the door of the furnace until the metal glows. After the metal glows and fuses thou shalt shut the door of the furnace. They shall pierce the outside of the furnace on the side opposite to the door with a hole; after they have pierced it thou shalt look in. If the metal has fused, thou shalt pour it out. The cooled product is uknû (blue glass).

Lee A. Oppenheim of the Oriental Institute of Chicago recently checked some of these early translations and confirmed, with the help of glass technologists who actually prepared the material in the laboratory as per directions given in the text, that the recipes concerned the preparation of coloured glasses.[c]

Then we have Pliny's account of the discovery of glass in Phoenicia and of glass-making in his time. "The restless ingenuity of man", writes Pliny, "was not long content to make glass from sand and soda (nitrum) only. He began to add the magnet stone also, for to it is attributed the property of attracting not only iron, but also molten glass. Similarly shining pebbles of many sorts were added to the melt, and then shells, and sands dug out of the earth. Some authorities state that in India glass is made from fragments of rock-crystal, for which reason Indian glass is beyond compare."[d] Further on: "This sand[e] . . . is ground in mortars or between mill-stones.

[a] Moore, 26–33. [b] Forbes, 137. [c] Oppenheim, 533.
[d] Pliny, *Natural History*, 36, 190–99.
[e] It refers to a fine white sand along the Italian coast from Cumae to Liternum, carried there by the river Volturnus.

It is then mixed with three parts of nitrum, by weight or measure, brought to a state of fusion, and transferred to another furnace, in which a mass called hammo-nitrum is formed. This is fused for a second time and *vitrum purum* is obtained, a mass of colourless glass."

The various ingredients for glass-making enumerated by Pliny include, besides sand and soda, limestone (*magnea lapis*), pebbles (*calculi*), shells (*conchae*), and excavated sands and sandstones (*fossiles harenae*). Pliny also mentions a red opaque glass called 'haematinum', white glass and glass of every colour, which provide a tractable material, unsurpassed in suitability, for mosaic patterns. On the whole, this great encyclopaedist of the first century A.D. has left us a succint and reliable record of ingredients and processes involved in glass-making in ancient times.

For any further information on ancient glass such as detailed chemical composition, the colorants used, temperatures for making and working with glasses, furnaces and crucibles, the quality of the glass and various techniques employed, such as mould-pressing, cold-cutting, core-winding, cane code etc., recourse to scientific investigations of glass objects by the best techniques currently available is indispensable.

ANALYSIS BY CHEMICAL, SPECTROGRAPHIC AND ELECTRON BEAM PROBE METHODS

In 1797–98, Martin Heinrich Klaproth, the discoverer of uranium, initiated a new field of research on ancient glass by analyzing a few pieces of Roman mosaic glass found in Capri. But his example was not emulated for a long time due both to the paucity of ancient glass objects as archaeology had not yet come into its own and to the expensive nature of chemical analysis. Before systematic analyses of ancient glass objects undertaken by Bernhard Neumann and his associates from 1925, there were very few reports of chemical analyses. For example, Benrath and his co-workers, during 1869 to 1884, examined a number of ancient glass samples and reported chemical analyses of 14 specimens, of which 10 were of Egyptian and Roman origin. Donald Campbell reported on ancient Jewish glass. Henrich and Roters analyzed specimens from 6 Roman glass vessels. Parodi gave 28 analyses—12 Egyptian specimens of the 12th, 18th and later Dynasties, 15 Islamic from 7th to 14th century A.D. and 1 Byzantine specimen. Chemical analysis of a specimen from a Babylonian glass vessel of the first half of the first millennium B.C. was given by Rathgen in 1921. These and a few other analyses of this period have been reviewed by Turner. Most of these early analyses are now of little value either because the weathered surface layers and contaminants were not properly removed, or all the ingredients such as MgO and K_2O which have considerable significance were not determined, or because selections were made of samples of unknown or questionable dates.

During 1925–29, Neumann[a] and his associates went thoroughly into the job and

[a] Neumann and Kotyga reported 38 analyses—12 Egyptian of the 18th Dynasty Tell-el-Amarna period, 12 Alexandrian glasses of which 10 were from Elephantine Islands of date 200–100 B.C. and 14 Roman glasses from Mainz and Cologne. Neumann (1) gave analyses of 15 glasses—2 from 1500 B.C. Egypt, 8 Roman glasses of 2nd century A.D. from Salona and 5 Arabian glasses dated 9th century

analyzed some 69 well-dated glass specimens typical of the second millennium B.C. from the 18th Dynasty graves and Mesopotamian temples, Hellenistic Egypt of first to second century B.C., the Babylonian finds from Nippur of the third century B.C., of the Rhine province during the Roman period and Arabian glass of 9th century A.D. During 1936–38, Patrick Ritchie and Marie Farnsworth carried out a series of spectrographic analyses of Far Eastern and also the 18th Dynasty Egyptian glasses, which, along with chemical and spectrographic analyses by other workers, formed the basis of an excellent study by H. C. Beck and C. G. Seligman on Far Eastern glasses. During the last forty years analytical data on ancient glass, by methods of wet chemistry as well as by spectrography, flame photometry, colorimetry, electron-beam probe method and x-ray diffractometry have been greatly enriched by W. E. S. Turner of the University of Sheffield, Wilhelm Geilmann of Mainz, Mikhail A. Bezborodov of Leningrad, Robert H. Brill of the Corning Museum of Glass, E. V. Sayre of the Brookhaven National Laboratory and R. W. Smith of the International Committee on Ancient Glass and several other workers. Matson, Turner, Sayre and Smith have at different times surveyed the results of previous analyses with a view to distinguishing patterns and recognizing compositional categories, if any, of ancient glass from different manufacturing centres in different periods of time.

Methods of analyses by wet chemical processes are well known, so are those by the optical spectrography. Where sufficient quantities of sample necessary for chemical analysis are not available, optical spectrography provides a satisfactory answer, and, as has already been stated, the rare and unsparable glass objects from the Far East were analyzed mostly by the spectrographic methods by Marie Farnsworth and Patrick Ritchie with considerable extension of our knowledge in this area.

ELECTRON BEAM PROBE

A new and powerful technique of microchemical analysis by electron beam probe, developed around 1948–49 and largely applied in the study of metals, has recently been tried successfully in the analysis of ancient glass.[a] The method lends itself to non-destructive quantitative analysis of small regions of glass objects, identification of opacifiers, analysis of stones and metallic intrusions and weathering crusts and to measurements of concentration gradients.

The method consists in directing a beam of electrons produced by an electron gun on to the glass sample to be analyzed (Fig. 4). The beam is sharply focussed by the electromagnetic lenses through which it has to pass. The focussing is so sharp that the area of the sample exposed to the beam is as small as 1 or 2 μ (0.001–0.002 mm) in diameter, thus permitting chemical analysis of objects too small to be seen by the naked eye. The striking electron beam produces fluorescent x-rays from the sample, which are then analyzed by the x-ray spectrometer and graphically recorded

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A.D. from Sumarra. Neumann (3) made available 6 analyses of Babylonian-Assyrian glasses from Nippur (250 B.C.). His studies (4) on coloured glasses include 4 specimens from Gorub Medined, Egypt (1500 B.C.), 2 from Nippur, Babylon (1500 B.C.) and 2 Roman specimens from Sacrau dated 300 A.D. Some of his analyses are included in the tables to follow.

[a] Brill and Moll, 293–302.

by the electron counter technique. The elements present in the sample can be readily ascertained from the wavelength record, and the intensities which can be determined by the counting of the pulses will provide quantitative estimation of their relative concentrations. The small number of x-ray lines offer a decided advantage over optical

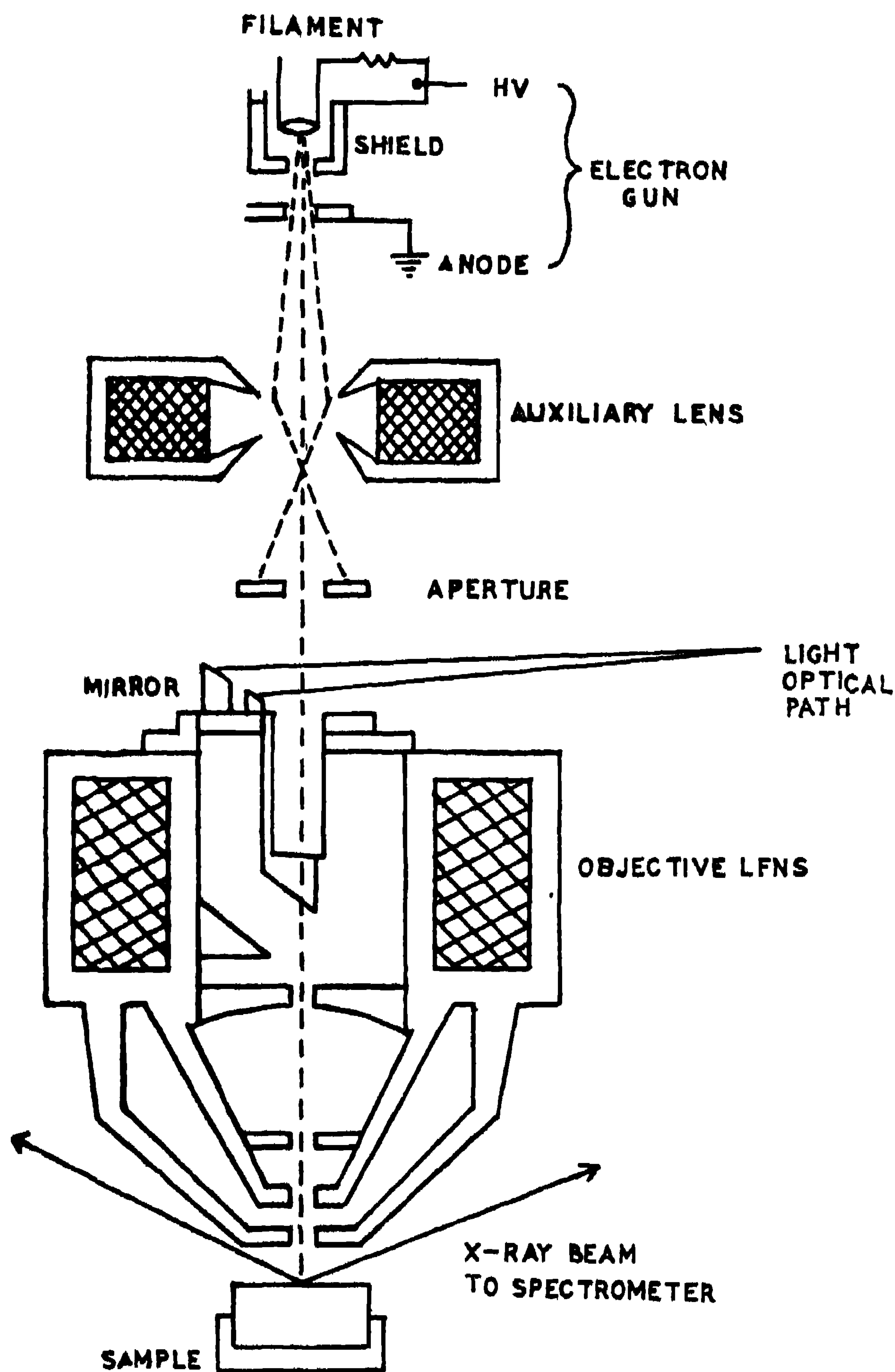


Fig. 4—Electron-Beam Probe Method.

spectrography with its numerous spectral lines. A microscope is attached to the unit to enable viewing of the sample and adjusting its different areas for exposure to the electron beam.

SOME RESULTS OF ANALYSIS

The percentage chemical compositions of Egyptian, Mesopotamian, Assyrian, Alexandrian and Babylonian glasses belonging to the second and the first millennium

B.C., Roman glasses of first to sixth century A.D., ancient glasses from the Indian sub-continent, South-East Asia and the Far East and Arabian, Central Asian and West European glasses of medieval times are given in Tables I–VII. For purposes of easy comparison, the composition percentages have been arranged, following Brill and other recent workers, under major constituents (SiO_2, Na_2O, CaO), minor constituents (K_2O, MgO, Al_2O_3, Fe_2O_3, MnO), colouring agents (CuO, CoO, Sb_2O_3) and other oxides and elements (PbO, SnO_2, As_2O_3, BaO, P_2O_5, SO_3, Cl, H_2O, etc.) present in traces. In the case of potassium and lead glasses of which a few examples have been shown in the tables, these should be taken as major constituents although the order has not been changed. The total alkalies, alkaline earths and R_2O_3 and the ratios Na_2O/K_2O, CaO/MgO have also been shown at the bottom of each table.

Most of the 70 samples selected represent soda-lime glass. Considering the long span of time and the wide geographical distribution of the glass-making centres, the similarities in the chemical compositions and in their minimum and maximum limits are indeed striking. Compositionally, the samples compare favourably with modern soda-lime glass for common use, as will appear from Table VIII. This is, however, not surprising in view of the eutectic mixture in the soda-lime-silicate system being approximately comprised of 73% SiO_2, 22% Na_2O and 5% CaO.

Roles of Various Constituents

SILICA, ALKALIES AND LIME

Before dealing with the characteristics of glasses of the different periods and cultural regions as reflected in the tables, it may be useful to keep in view the roles of the various constituents in determining the qualities of glass and their colours. It is well known that SiO_2 can itself pass into the glassy state at over 1713°C, unattainable at the furnaces in use during the ancient times. Addition of alkalies lowers the temperature below 800°C, thus enabling glass-making at ordinary furnaces; but a pure sodium silicate glass is soluble in water and useless for practical purposes. Excessive alkalies, through attack by water, make glass less durable. The addition of lime not only stabilizes the glass but contributes to its strength. The presence of CaO up to 15% makes glass durable and improves both its tensile and bending strength.[a] Glass containing too much lime, however, tends to devitrify and hardens rapidly on cooling from the molten state. A 12–14% CaO content makes it set very quickly. This property is useful for the drawing of sheet glass and for the hand production of vessels, but unsuitable for blown wares.

OXIDES OF ALUMINIUM, MAGNESIUM, BORON, ZINC AND MANGANESE

Small quantities of Al_2O_3, MgO, B_2O_3 and ZnO also contribute to the durability of glass. Magnesia has another advantage; when used to replace lime in moderate amount, say up to 3%, it reduces the annealing temperature and gives a longer temperature range to facilitate manipulation with glass in the forming operation. Fe_2O_3, which is present in sand as an impurity in the form of hydrated oxide,

[a] *Thorpe's Dictionary of Applied Chemistry*, 554.

TABLE I

Percentage Chemical Compositions of Some Ancient Glasses in the Near East during the Second and the First Millennium B.C.

Cultural Region	EGYPT							
Place	Thebes	Tell-el-Amarna				Medinet-Habou		
Date	12th Dyn. 1989–1776 B.C.	18th Dynasty 1580–1350 B C.				18–20 Dyn. 1200 B.C.	20th Dyn. 1250–1150 B.C.	20–22 Dyn. 1200–1000 B C
Colour	Transparent	Dark blue opaque	Colourless transparent	Blue	Blue	Blue	Blue	Bluish green
No.	1	2	3	4	5	6	7	8
Major constituents								
SiO_2	68.2	61.7	63.86	64.06	66.98	66.27	60.1	66.27
Na_2O	20.2	17.63	22.66	15.47	14.32	16.12	29.10	10.48
CaO	4.9	10.05	7.86	8.56	10.45	9.02	3.7	9.59
Minor constituents								
K_2O	2.0	1.58	0.80	1.25	0.51	0.82	1.4	4 11
MgO	1.0	5.14	4.18	2.73	4.27	2.03	2.0	2.40
Al_2O_3	3.2 }	2.45	0.65	3.51	2.13	2.71	3.1 }	0.92
Fe_2O_3		0.72	0.67	1.71	0.50	0.85		2 12
MnO	0.3	0.47	trace	0.163	0.38	0.17	0.4 (MnO_2)	1.52
TiO_2				0.08	0.09	0.12		0.14
Colouring agents								
CuO		0.32		0.005	0.01	0.13		1.31
CoO				0.55	0.075	0.29		
Sb_2O_3				0.05	nil	0.03		
Other oxides, elements								
PbO				0.012	0.05	0.05		0.14
SnO_2				0.02	trace	0.01		0.01
As_2O_3				0.006	0.003	0.01		
NiO				0.075	0.03	0.05		
P_2O_5				0 213	0.13	0.23		0.38
SO_3				0.16	0.18	0.31		0.08
Cl				1.17		0.88		0.53
H_2O				0.27	0.10	0.05		0 07
$Na_2O.K_2O$	22.2	19.21	23.46	16.72	14.83	16.94		14.59
CaO.MgO	5.9	15.19	12.04	11.29	14.72	11.05		11.99
R_2O_3	3.2	3.17	1.32	3.20	2.63	3.56		3.04
Na_2O/K_2O	10.1	11.1	28.3	12.3	28.1	19.7		2.6
CaO/MgO	4.9	2.0	1.9	3.1	2.4	4.4		4.0

1, 7. Parodi. 2, 3. Neumann and Kotyga. 4, 5, 6, 8. Geilmann *et al.*

TABLE I (*contd.*)

Percentage Chemical Compositions of Some Ancient Glasses in the Near East during the Second and the First Millennium B C.

Cultural Region	EGYPT			MESOPOTAMIA	
Place		Alexandria, Elephantine Island		Nippur, Bell Temple	
Date	20–22 Dyn. about 800 B.C.	1st to 2nd cent. B.C.		1400 B.C.	
Colour	Violet	Turquoise opaque	Green opaque	Lapis lazuli	Turquoise opaque
No.	9	10	11	12	13
Major constituents					
SiO_2	63.53	68.12	60.83	65.03	64.41
Na_2O	14.31	18.90	28.98	17.37	13.98
CaO	10.12	4.20	1.51	5.65	6.19
Minor constituents					
K_2O	3.25	1.91	—	1.68	2.37
MgO	2.05	1.28	1.53	2.52	5.59
Al_2O_3	2.25	1.94	2.22	2.13	1.52
Fe_2O_3	1.27	0.67	0.57	0.97	1.36
MnO	2.13	—	—	0.65	—
TiO_2	0.10	—	—		
Colouring agents					
CuO	0.08	2.73	3.01	1.94	2.60
CoO	—	—	—	0.93	—
Sb_2O_3					
Other oxides, elements					
PbO	—	—	0.93	0.19	—
SnO_2	0.08				0.32
BaO					
P_2O_5	0.27				
SO_3	0.12			1.70	1.28
Cl	0.42				
H_2O	0.11				
$Na_2O.K_2O$	17.56	20.81	28.98	19.05	16.35
CaO.MgO	12.17	5.48	3.04	7.17	11.78
R_2O_3	3.52	2.61	2.79	3.10	2.88
Na_2O/K_2O	4.4	9.9	α	10.3	6.0
CaO/MgO	4.9	3.3	1.0	2.2	1.1

9. Geilmann *et al.* 10, 11. Neumann and Kotyga. 12, 13. Neumann (4).

TABLE I (*contd.*)

Percentage Chemical Compositions of Some Ancient Glasses in the Near East during the Second and the First Millennium B.C.

Cultural Region	ASSYRIA			ACCAD-BABYLONIA		CRETE		GREECE
Place	Nimrud			Nippur		Knossos		Agora, Athens
Date	715 B.C.	700–630 B.C.		250 B.C.		c. 1400 B.C.		2nd cent. B.C.
Colour	Opal blue	Nearly colourless	Sealing wax red	Bright pink	Bright green	Dark blue	Opaque light blue	
No.	14	15	16	17	18	19	20	21
Major constituents								
SiO_2	62.60	71.54	39.50	71.14	61.18	64.41	64.40	64.68
Na_2O	16.54	12.70	9.71	10.81	12.90	12.75	14.40	18.10
CaO	5.68	4.82	4.40	5.26	7.10	7.53	9.90	6.80
Minor constituents								
K_2O	2.91	0.88	1.91	1.30	2.88	2.08	2.40	0.49
MgO	5.31	3.07	—	5.40	4.92	4.59	2.60	0.80
Al_2O_3	0.38	0.48	4.35 }	2 48	2.06	2.58	2.10	2.0
F_2O_3	0.27	0.91		0.72	2.15	1.44	0 40	≈ 0.5
MnO	n.d.	0.025		1.04	4.37	2.75	0.25	0.x
TiO_2	n.d.	0.19					trace	≈ 0.1
Colouring agents								
CuO	2.61	—	13.58 (Cu_2O)	0.55	0.52	1.20	1.60	≈ 0.5
CoO	—	—	—	—	—	—	—	≈ 0.002
Sb_2O_3	n.d.	0.25	4.07				0.50	0.87 (Sb_2O_5)
Other oxides, elements								
PbO	—	—	22.80					≈ 0.5
SnO_2	0.44		0.32					≈ 0.1
P_2O_5	0 15	0.11				n.d.		n.d.
SO_3	1.20	0.99		0.87	1.67	1.00	2.0	—
H_2O	1.85	4.58					n.d.	
$Na_2O.K_2O$	19.45	13.58		12.11	15.78	14.83	16.80	18.59
CaO.MgO	10.99	7.89		10.66	12.02	12.12	12.50	7.60
R_2O_3	0.66	1.39		3.20	4.21	4.02	2.50	2.50
Na_2O/K_2O	5.7	14.4		8.3	4.5	6.1	6.0	36.9
CaO/MgO	1.1	1.6		1.0	1.4	1.6	3.8	8.5

n.d. = not determined. ≈ approx.

14, 15, 16. Turner (2). 17, 18, 19. Neumann (3). 20. Turner (4).

21. Brill (2); spectrographic determinations have revealed the presence of Ag—0.005%, B_2O_3—0.01%, Cr_2O_3—0.002%, NiO—0.01% and ZnO—0.01%.

TABLE II

Percentage Chemical Compositions of Some Ancient Roman Glasses during the First to the Seventh Century A.D.

Cultural Region	ROMAN AND FRANKISH GLASS FROM THE RHINE DISTRICTS							ALEXANDRIAN
Place	Bristol, England	Saalburg near Hamburg		Cologne	Bonn	Alzey	Carolingian	
Date	75–130 A.D.	2nd to 3rd cent. A.D.		3rd–4th cent. A.D.	2nd–4th cent. A.D.			200–300 A.D.
Colour	Pale yellow	Bluish green	Apple green	Yellowish green	Clear green blue			Colourless glass
No.	22	23	24	25	26	27	28	29
Major constituents								
SiO_2	69.1	69.07	68.77	69 05	67.97	69.93	64.20	58.38
Na_2O	16.2	17.80	19.55	19.62	17.12	19.87	19.01	16.70
CaO	8.2	7.84	6.61	7 86	7.62	6.13	7.07	5.88
Minor constituents								
K_2O	1.4	1.36	0 85	0.62	0.87	0.94	0.09	14.37
MgO	0 6	1.05	1.03	0.15	2.53	0.93	6.13	1.51
Al_2O_3	2 6	0.77	1.12	0.77	2.33	0.94	1.11	0.78
Fe_2O_3	0.49	0.98	0.66	0.75	0.35	0.33	0.99	0.53
MnO	1.10	0.66	0.183	0.16	0.42	0.20	0.74	1.18
TiO_2	—	0.05	0.08	0.08	0.14	0.09	0.15	0.14
Colouring agents								
CuO		0.11	0.05	0.11	—	—	—	—
CoO								
Sb_2O_3			0.11					
Other oxides, elements								
PbO		0.02						
SnO_2		0.01	trace					trace
As_2O_3		0.005	0.008					
NiO								
P_2O_5		0.18	0.097	0.15	0.19	0.24	0.16	0.083
SO_3	0.20	0 03	0.03	0.52	0.30	0.45	0.23	0.49
Cl		0.08	1.18	0.08	n.d.	n.d.	n.d.	0.30
H_2O								
$Na_2O.K_2O$	17.6	19 16	20.40	20.24	17.99	20.81	19.10	31.07
$CaO.MgO$	8.8	8.89	7.64	8 01	10.15	7.06	13.20	7.39
R_2O_3	3.09	1.75	1.78	1.52	2.68	1.27	2.10	1.31
Na_2O/K_2O	11.60	13.10	23.0	31.60	19.70	21.10	211.20	1.20
CaO/MgO	13.70	7.50	6.40	52.40	3 00	6.60	1.20	3.90

22. Cole, 46–47. 23–29. Geilmann *et al.*

TABLE II (*contd.*)
Percentage Chemical Compositions of Some Ancient Roman Glasses

Cultural Region	GREECE	U S.S.R.			BYZANTIUM			
Place	Agora, Athens	Komarov on the middle Dniester in Ukraine			Sardis	Sofia	Average chemical composition of Roman glass from Cologne, Bonn Mainz, Salonaeon, Split (Bezborodov)	Average composition of Roman glass (Caley)
Date	351–361 A.D.	3rd cent. A.D			Late Roman	6th cent. A.D.		
Colour	Colourless	Colourless	Pale greenish	Dark violet	Dichromatic: peasoup-green-deep magenta	Blue transparent		
No.	30	31	32	33	34	35	36	37
Major constituents								
SiO_2	70.00	68 00	67.23	67 52	67 00	67.12	68.10	68.56
Na_2O	16.18	19.79	18.10	17.75	18.20	17.59	18 63	17.97
CaO	5.70	6.20	9.17	6 28	5.80	8.37	6.98	6.76
Minor constituents								
K_2O	0 20	0 32	0.69	0 45	0.25	1.26	1.13	1 21
MgO	1.10	1.45	1.13	2.22	0.90	0.97	1.03	0.67
Al_2O_3	2.7	1.58	0.62	2.32	2.50	2.66	2.52	2 88
Fe_2O_3	1.0	1.85	2.08	1.30	2.30	1.39	0.81	—
MnO	0.08 (MnO_2)	0 57	0.99	1.69	0.60	0.37	0.50	—
TiO_2	0.70	—	—	—	0.06	—	—	—
Colouring agents								
CuO	0.01	—	—	—	0.05			
CoO	0.01	none	none	none				
Sb_2O_3	0.38				0.43			
Other oxides, elements								
PbO	0 01				0.04	0.27		
SnO_2	0.01				0.01	—		
As_2O_3								
NiO								
P_2O_5								
SO_3		0.10	0.05	0.28				
Cl								
H_2O								
$Na_2O.K_2O$	16.38	20 11	18.79	18.20	18.45	18.85	19 76	19.18
CaO.MgO	6 80	7.65	10.30	8.50	6.70	9.34	8.01	7.43
R_2O_3	3.70	3.43	2.70	3.62	4.80	4.05	3.33	2.88
Na_2O/K_2O	80 90	61.80	26.20	39.50	72.80	14.00	16 50	14.90
CaO/MgO	5.20	4.30	8.10	2.80	6 40	8.60	6 80	10.10

30. Brill (5), 58; spectrographic chemical analysis; SiO_2 found by diff., allowing approx. 0.8 for non-metals and 17.5% for Na_2O. 31, 32, 33, 36 & 37. Bezborodov and Abdurazakov, 66.
34. Brill (6); also contains Au—0.002%, Ag—0.06%, BaO—0.03%, SrO—0.20%.
35. Benrath (3); see also Forbes, V, 229.

TABLE III

Percentage Chemical Compositions of Some Ancient Glasses in Indian Sub-continent of the Period 5th century B.C. to 15th century A.D.

Cultural Region	INDIAN SUB-CONTINENT					
Place	Taxila		Kopia		Arikamedu	
Date	6th cent.–3rd cent. B.C.		3rd cent. B.C.–3rd cent. A.D.		1st cent. A.D.	
Colour	Haematinum	Light green	Green bead	Dull blue approaching indigo, about opaque	Deep violet	Glass lump (for bead-making)
No.	38	39	40	41	42	43
Major constituents						
SiO_2	39.79	68.34	67.13	73.60	73.62	66.69
Na_2O	10.02	17.76	19.61	2.10	1.30	14.30
CaO	2.81	8.44	3.03	3.90	1.96	4.60
Minor constituents						
K_2O	0.57	0.94	—	13.40	12.78	4.00
MgO	?	1.44	1.60	1.40	0.30	2.00
Al_2O_3	2.45	1.67	6.70	1.90	1.38	4.50
Fe_2O_3		1.20	1.50	1.10	3.84	1.30
FeO				2.00		
MnO	—	0.34	0.032	0.40	5.01	0.14
TiO_2			0.40			0.27
Colouring agents						
CuO			—			2.10
Cu	5.31		—			
CoO						
Other oxides, elements						
PbO	38.93				0.07	0.01
SnO_2	0.22					
BaO						0.09
P_2O_5						
SO_3						
H_2O		0.43				
$Na_2O.K_2O$	10.59	18.70	19.61	15.50	14.08	18.30
CaO.MgO	2.81	9.88	4.63	5.30	2.36	6.60
R_2O_3	2.45	2.87	1.53	5.00	5.22	5.80
Na_2O/K_2O	17.60	18.90	α	0.16	0.10	3.60
CaO/MgO	—	5.90	1.9	2 81	6.50	2.30

38, 39. Sana Ullah, *ASI/AR* (1922–23), 158. 40. Roy and Varshney, 366–68.
41. Subramanian, 19–20. 42. Lal (Dr) (11), 25, 26. 43. Lamb (2), 87.

TABLE III (*contd.*)
Percentage Chemical Compositions of Some Ancient Glasses in Indian Sub-continent of the Period 5th century B.C. to 15th century A.D.

Cultural Region	INDIAN SUB-CONTINENT				
Place	Ahichchatra		Nalanda	Nasik	
Date	1st cent. A D.		5th cent.–9th cent. A D.	100 B.C.–200 A D.	
Colour	Blue	Green	Light blue	Green	Bottle green
No.	44	45	46	47	48
Major constituents					
SiO_2	61.49	59.56	62.61	70.74	65.38
Na_2O	15.32	14.19	17.85	15.80	7.88
CaO	6.60	6.54	6 95	2.11	11.88
Minor constituents					
K_2O	2.67	2.41	5.04	2.94	1 06
MgO	4 61	4.34	4.17	0.26	1.48
Al_2O_3	0.66	0 05	2.05	6.13	5.75
Fe_2O_3	5.29	5.40	1 61	1.54	4.78
FeO			—	—	1.73
MnO	—	0.06			
TiO_2					
Colouring agents					
CuO	2.39	1.82	0.57	—	
Cu					
CoO					
Other oxides, elements					
PbO		4.23			
SnO_2					
BaO					
P_2O_5	1.94	1.36			
SO_3					
H_2O					
$Na_2O.K_2O$	17 99	16.60	22.39	18.74	8.94
CaO.MgO	11.21	10.88	11.12	2.37	13.36
R_2O_3	5.95	5.45	3.66	7.67	10.53
Na_2O/K_2O	5.70	5.90	3.50	5.30	7.40
CaO/MgO	1.44	1.50	1.70	8.00	8.00

44, 45. Lal (Dr) (1), 25.
46, 47. Sana Ullah, *ASI/AR* (1922–23), 158; (1930–34), 300. See also page 190.
48. Lal (Dr) (2), 52–58.

TABLE IV
Percentage Chemical Compositions of Some Ancient Glasses in South-East Asia, China and Japan

Cultural Region	SOUTH-EAST ASIA			CHINA	JAPAN	
Place	Kampong, Salangor, Malayasia	Pasemah, Sumatra	Oc-eo, Mekong Delta	Han Chu, Honan	Kofun period	
Date	1st cent. B.C (?)		Early A.D.	3rd cent. B.C.	3rd–6th cent. A.D.	
Colour				Blue with white inlay	Pale green	Dark blue
No	49	50	51	52	53	54
Major constituents						
SiO_2	63.28	53.34	59.30	40.90	60.47	65.60
Na_2O	18.00	24.00	20.60	4.50	14.91	15.63
CaO	7.00	2.88	3 60	4 50	6.68	7.18
Minor constituents						
K_2O	1.80	1.79	—	—	3.67	3.47
MgO	2.16	0.75	1.81	—	0.42	2.43
Al_2O_3	4.70	8.95	9.40	4.40 }	12.04	4.01
Fe_2O_3	1.60	3.52	1.59		0.18	0.24
MnO	0.05	n.d.	0.13	—	0.56	0.004
TiO_2	0.20	n.d.	n.d.	—	0.34	0.09
Colouring agents						
CuO	1.00	4.72	2.38	trace	0.42	0.24
CoO	n.d.	n.d.	n.d.	—		0.003
Other oxides, elements						
PbO	0.10			24.50	0.27	0.07
SnO_2	trace			—		
BaO	0.10	n.d.	n.d.	19.20		
P_2O_5						
SO_3				—	0.17	0.44
H_2O						
$Na_2O.K_2O$	19.80	25.79	24.36	—	18.58	19.10
CaO.MgO	9.16	3.63	5.11	—	7.10	9.61
R_2O_3	6.30	12.47	6.44	—	12.22	5.25
Na_2O/K_2O	10 00	13.40	α	—	4.10	4.50
CaO/MgO	3.20	3.80	1.20	—	15.90	2.90

49, 50, 51. Lamb (2), 87. 52. Beck and Seligman. 53, 54. Yamasaki.

TABLE V

Percentage Chemical Compositions of Arabian Glasses of the Period 4th to 14th Century A D.

Cultural Region	ARABIAN				
Place	Beth She'arim, Syria	Samara (Excavations, Hertfeld, '10–'13)			
Date	4th–7th cent A.D.	8th cent. A.D.	9th cent. A.D.	10th cent A.D.	14th cent. A D.
Colour	Giant glass slab	Dark blue green	Emerald green	Deep blue	
No.	55	56	57	58	59
Major constituents					
SiO_2	57.50	71 40	65.86	69.25	69.43
Na_2O	12.90	17.00	12.84	13.66	13.99
CaO	15.90	2.70	5.95	6.86	7.95
Minor constituents					
K_2O	2.50	0.30	2.70	2.73	2.31
MgO	2.60	0.80	4.55	1 94	2.23
Al_2O_3	3.40	4.70	2.16	1.22	0 69
Fe_2O_3	1.10	2 00	1.19	3.01	0.69
MnO	0.80	0.30	1.09	0.294	2.17
TiO_2				0 10	0.06
Colouring agents					
CuO		0.10	2.66	0.68	0.06
CoO				0.155	0.002
Other oxides, elements					
BaO					
B_2O_3					trace
NiO				0.007	
P_2O_5				0.22	2.17
SO_3		0.10	1.72	0.04	0.04
$Na_2O.K_2O$		17 30	15.54	16.39	16.30
CaO.MgO		3.50	10.50	8.80	10.18
R_2O_3		6.70	3.35	4.23	1.38
Na_2O/K_2O		56.70	4 80	5.00	6.10
CaO/MgO		3.40	1.30	3.50	3.60

55. Brill (7), 91. 56 Matson (1). 57. Neumann (1).
58, 59. Geilmann *et al.*, 148, 152.

TABLE VI

Percentage Chemical Compositions of Some Central Asian Glasses of the Period 7th to 14th Century A.D.

Cultural Region	CENTRAL ASIA (RUSSIA)					
Place	Orbeti, Georgia	Kuva, Fergana, Uzbek	Akhsiket on the Syr-Daria, Central Asia			Natbeuri, Georgia
Date	7th–8th cent. A D.	10th cent. A.D.	10th–12th cent. A D.			13th–14th cent. A.D.
Colour		Dark green	Bright yellow	Opaque dark green	Transparent greenish	
No.	60	61	62	63	64	65
Major constituents						
SiO_2	58.07	65.77	67.30	60.95	61.76	60.88
Na_2O	15.00	0.12	7.12	0.16	13 62	18.15
CaO	9.50	7.17	6.61	2.02	9.81	11.12
Minor constituents						
K_2O	6.00	16.41	8.85	0.60	4.30	2.00
MgO	1.71	5.87	4.70	1.00	3.95	2.00
Al_2O_3	8.48	2.97	3.14	5.78	2.83	1.41
Fe_2O_3	0.62	1.75	1.53	6.10	1.10	1 83
MnO	trace	—	0.85 (Mn_2O_3)	22 67 (Mn_2O_3)	1.06 (Mn_2O_3)	0.24 (Mn_2O_3)
TiO_2				0.30	0.16	
Colouring agents						
CuO						
CoO						
Other oxides, elements						
BaO				0.75		0.65
B_2O_3						
NiO						
P_2O_5				0.04		
SO_3		0.19	0.22	0.14		
$Na_2O.K_2O$	21.00	16.53	15.97	0.76	17.92	20.15
CaO.MgO	11.21	13.04	11.31	3.02	13.76	13.12
R_2O_3	9.10	4.72	4 67	11.88	3.93	3.24
Na_2O/K_2O	2.50	0.007	0.80	0.30	3.20	9.10
CaO/MgO	5.60	1.30	1.40	2.00	2.50	5.60

60, 61, 62, 63, 64, 65. Bezborodov and Abdurazakov, 67, 68.

TABLE VII

Percentage Chemical Compositions of Some Medieval West European Glasses of the Period 11th to 13th Century A.D.

Cultural Region	WESTERN EUROPE (MEDIEVAL) (German and French flat and hollow glass)				
Place	Werla	Weeze	Hannover	Cologne	Reims Cathedral
Date	*c.* 1000 A.D.	*c.* 1120 A D.	*c.* 1400–1500 A.D.	*c.* 1500–1600 A.D.	13th cent. A.D.
Colour	Yellow				Blue
No.	66	67	68	69	70
Major constituents					
SiO_2	53 55	48.46	49.68	72.01	53.90
Na_2O	2.83	0.79	0.58	18.06	1.90
CaO	22.59	22.96	21.07	5.56	19.30
Minor constituents					
K_2O	7.33	12.00	21.20	0.66	12.20
MgO	6.95	3 54	2 29	1.77	4.10
Al_2O_3	0.11	6.12	0.82	1.19	3.90
Fe_2O_3	1.19	0.55	0.21	0.27	0 79
MnO	1.13	1.51	1.25	0.15	3.00
TiO_2	0.09	0.03	0.14	0.04	0.20
Colouring agents					
CuO					0.13
CoO					0.25
Other oxides, elements					
BaO					
B_2O_3					0 02
NiO					
P_2O_5	3.31	3.65	2.36	0.04	
SO_3					
Na_2O K_2O	10.16	12.79	21.78	18.72	14.10
CaO.MgO	29.54	26.50	23.36	7.33	23.40
R_2O_3	1.30	6.67	1.03	1 46	4.69
Na_2O/K_2O	0.39	0.07	0 03	27.30	0.15
CaO/MgO	3.30	6.50	9.20	3.10	4.70

66, 67, 68, 69, 70. Geilmann *et al.*, 148, 152.

TABLE VIII

Summary of Comparison of Chemical Compositions of Ancient Glass of Different Culture Areas with those of Modern Glass

	Modern soda-lime glasses		Egyptian–Mesopotamian (2nd–1st mill. B.C.)	Roman (1st–6th cent. B.C.)	Indian (5th cent. B.C.–15th cent. A.D.)	Arabian (4th–14th cent. A.D.)
	1	2	3	4	5	6
Major						
SiO_2	65 20–74.00	61.90	60.83–71.54	64.20–70.00	59.56–73.62	57.50–71.40
Na_2O	13.78–17.88	6.16	10.48–22.66	16.18–19.87	7.88–19.15	12.84–17.00
CaO	6.83–9.48	17.95	3.70–10.45	5.70–9.17	2.11–11.88	2.70–15.90
Minor						
K_2O	0.98–3.41	1.13	0.80–4.11	0.09–1.36	0–5.04	0.30–2.73
MgO	0.12–0.21	6.38	1.00–5.59	0.60–6.13	0.26–4.61	0.80–4.55
Al_2O_3	0.45–3.52	4.44	0.38–3.51	0.62–2.70	0.05–7.00	0.69–4.70
Fe_2O_3	0.06–2 20	1.66	0 27–2.15	0.33–2.30	1.20–5.40	0.69–3.01

1. *Thorpe's Dictionary of Applied Chemistry*, V, 4th edition, 1947, p. 556. Based on analyses of continental made soda-water siphon, pressed meat jar, colourless automatic machine made container, colourless automatic machine made bottle and dark-green beer bottle made on automatic feeder-fed machine.
2. Thorpe, *op. cit.*, continental type hand-made champagne wine bottle.
3. Samples Nos. 7, 11 & 16 (Table I) are excluded.
4. Sample No. 29 (Table II) is excluded.
5. Samples Nos. 38, 41 & 42 (Table III) are excluded.

limonite (Fe_2O_3, H_2O), is least desired except for colouring purposes, for it imparts a dirty greenish colour to glass. For good quality colourless containers its amount may be 0.04%, for ordinary tableware up to 0.1%, for window glass 0.1–0.15% and for dark green bottle glass 2.3% or more.[a]

Manganese dioxide which occurs in nature as the mineral pyrolusite has a number of parts to play. As an oxidizing agent it oxidizes ferrous iron to ferric and removes the dirty green colour due to ferrous ions. Moreover, under oxidizing conditions, manganese gives rise to a purple colour with sodium and a violet one with potassium glasses. In some valency states, it also produces an amethyst colour. With ferric oxides, depending on relative percentages, manganese produces different shades of colour of red, brown and purple under oxidizing or reducing conditions during melting operations.

[a] *Thorpe's Dictionary of Applied Chemistry*, 558.

COLOURING AGENTS

As to the colouring agents, mention has been made of the colouring effects of iron oxides. Many glasses containing not more than 0.5% iron oxides appear greenish blue to light sea-green. In 1779 Gmelin noticed that iron-containing glasses of the same composition but made under reducing conditions appeared blue. A Roman gladiator beaker containing about the same amount of iron is amber-coloured. Such varied colour effects are due to the simultaneous presence of FeO and Fe_2O_3, the former dispersing ferrous ions (Fe^{++}) and the latter the ferric ions (Fe^{+++}). Fe^{++} ions being strong absorbers of the red end of the spectrum tend to colour glass blue, whereas Fe^{+++} ions being weak absorbers of the violet region of the spectrum will give rise to a yellow colour. Greenish blue is the resultant effect. If the balance is upset in favour of Fe^{++} in a reducing atmosphere, the total colour effect will be blue. Further reduction will lead to the formation of an iron polysulphide complex responsible for amber colour.[a] Higher percentages of Fe_2O_3 with preponderance of Fe^{+++} ions give various shades of yellow to green as follows: 0.73%—bright sea-green; 1.23%—bright yellowish green; 5.56%—deep yellowish green; 8.23%—a dark olive-green, but still transparent; 11.12%—a dark olive-green opaque in thick layers.[b]

Copper oxides may be formed of monovalent cuprous (Cu^{+}) ions or divalent cupric (Cu^{++}) ions. The latter represented in CuO produces a blue colour in glass. Cuprous oxide Cu_2O, on the other hand, is responsible for an excellent ruby glass. Glass containing CuO when melted in a reducing atmosphere may develop such ruby red colour due to the formation of cuprous oxide crystals or to the precipitation of metallic copper itself in uniform suspension throughout the glass mass.

For the development of blue colour cobalt oxide is very effective. One part of CoO in 1000 produces a deep blue, one part in 100,000 a faint blue colour and one part in a million a bluish tint still detectable in a thickness of several centimetres.[c] Unlike copper oxides which are dispersed in glass as it were in a colloidal solution, miscibility of cobalt oxide is more like a solution, explaining the preferability in modern times of cobalt to copper in the making of blue glass.

White opaque or opal glasses are produced with the help of opacifying agents. The opacity is due to the separation from the glass mass either of finely divided SiO_2 or some metallic oxides or both. Excess of silica or oxides of antimony, tin and aluminium may lead to white opaque glass. In the case of antimony, the metal produces in alkali-lime-silica glass a compound $Ca_2Sb_2O_7$ or $Ca_2Sb_2O_6$. In coloured opal glass, antimony in the presence of lead forms a colorant-opacifier lead pyroantimonate, $Pb_2Sb_2O_7$, which is responsible for a beautiful yellow opaque glass.[d]

Lead, besides its role in developing a colorant-opacifier with antimony, also found an important use in the production of red colours. The colours are actually due to the precipitated crystals of Cu_2O, but this precipitation is facilitated to a greater extent in a lead-containing glass than in a soda-lime glass without lead.

Nickel oxide produces a reddish brown colour in a sodium glass and a violet colour in a potassium glass.

[a] Brill (4), 126. [b] Angus-Butterworth, 112–18.
[c] *Thorpe's Dictionary of Applied Chemistry*, 561. [d] Brill (8), 255–56.

Complexity of Composition of Ancient Glass as Revealed by Analyses

MAJOR CONSTITUENTS

(a) *Silica*: Reverting to the analyses given in Tables I–VII, the percentage of SiO_2 shows large variations in glasses of the 2nd and the 1st millennium B.C. than it does in Roman, and to some extent in Indian and Arabian, glasses. The average of 11 Egyptian samples (Nos. 1–11) is 64.53%. Turner's average for 6 Theban and Gorub samples is 65.1; that for seven 18th Dynasty samples 62.19 and that for 17 samples selected in his table 63.6%. The seven Mesopotamian samples (Nos. 12–19 except 16) give an average of 65.76% which agrees with Turner's mean value 65.84% based on 6 samples. Regarding Roman glasses, the average 68.07 of 13 samples (Nos. 22–35 except the Alexandrian specimen No. 29) compares well with Bezborodov's 68.1 and Caley's 68.56. Ten Indian samples give a mean of 66.92 (Turner's value 67.70), but a number of samples from Taxila, Kopia, Arikamedu, Nalanda contain over 70 per cent. The average of four Arabian glasses is 68.97. These averages point to the use of a higher percentage of SiO_2 in Mesopotamian and Indian glasses than in the contemporaneous Egyptian variety and to a somewhat higher percentage during Roman times. The medieval West European samples record lower values.

Variations in total alkali percentages are wide. In Egyptian glasses Na_2O ranges from 10.48 to 29.10 and total alkali from 14.59 to 30.50, with an average at 20.53. For Mesopotamian glasses, this average is 15.88, indicating use of somewhat smaller percentages of alkalies. For Roman glasses, the proportion is again higher—19.76 (Bezborodov) and 19.18 (Caley), approaching nearly the Egyptian value. In Indian glasses the alkalies fluctuate from 8.94% to 22.89%, giving the average of the selected samples at 17.1. The average of 16.4 for four Arabian specimens is quite comparable to the Mesopotamian figure. In medieval France and Germany, the average alkali percentage of 15.51 (Nos. 66–70) shows a marked deviation from the Roman proportion. Alkalies in Central Asian glasses average at 18.28%.

Not much information is available about special grades of sand, if any, that might have been used at ancient glass-making centres. Pliny and other writers have referred to the excellent quality of sand obtained from the mouth of the River Belus on the Syrian coast and the River Volturnus in Southern Italy. But practically nothing is known about the type of sand used by the glass-makers of Egypt and elsewhere except what might be guessed from a few analyses of sand from ancient factory sites. Some of these analyses are given in Table IX.

High silica content and low percentage of Fe_2O_3 for the Belus sample bear out the ancient estimate of sand from this area. For the Egyptian sands, as reported by Parodi and Lucas, separate estimates for iron oxide have not been given. As already noted, the aluminium and iron contents of ancient glass were usually obtained from the sands used. There is a wide variation in the lime content, some of the Egyptian samples containing as low a percentage as 0.67 and as high as 18.86. In the final make-up, this percentage is of course reduced by the addition of alkalies, but wide variations should still be noticeable as the results of glass analyses indicate.

TABLE IX

Composition of Sand from Some Ancient Glass-making Sites

	EGYPT						SYRIA-PALESTINE		
	Karnak	Fayoum	Achmounein	Pyramids	Assouan	Tell-el-Amarna	Mouths of Belus, Haifa in the Bay of Acra		Haifa
	1	2	3	4	5	6	7	8	9
SiO_2	83.61	95 22	96.74	82.35	93.78	60.46	80.98	80.8	76.40
Al_2O_3	1.32	1.86	0.62	1.45	3.59	2.25	3.58	3.92	n.d.
Fe_2O_3						1.73	0.12	0 12	n d.
CaO	12.01	1.85	1.91	8.40	0.67	18.86	9.0	8.82	10.73
MgO	1.23	0.09	0.57	tr.	tr.	0.83	—	—	0.75
Na_2O	—	—	—	—	—	0.30	—	—	n.d.
NaCl	—	—	—	0.19	tr	—	—	—	—
K_2O	—	—	—	—	—	0.74	—	—	n.d.
MnO	—	—	—	—	—	0.02	—	—	n.d.
TiO_2	—	—	—	—	—	0.44	—	—	n.d.
P_2O_5	—	—	—	—	—	0.08	—	—	n.d.
SO_3	—	—	—	0 22	nil	0.05	—	—	n.d.
Moisture	1.57	1.02	0.11	1.15	0.37	0.42	—	—	0.40
Loss on ignition	—	—	—	6.56	1 12	13.90	6.3	6.6	7.80

1, 2, 3. After Parodi. 4, 5. After Lucas. 6, 9. After Preston, Jeffkins and Warr.
7, 8. After Heinmann and Berl. (Reproduced from Turner (5), 281T.)

(b) *Alkalies*: The preponderance of soda over potash in total alkalies in ancient glasses is clearly demonstrated by the fact that out of the seventy analyses selected only nine (Nos. 29, 41, 42, 61, 62, 66–68, 70) have potash in excess of soda. The potash content in most ancient Egyptian glasses is very low, the Na_2O/K_2O ratio varying from 9.9 to 28.1 in seven cases and showing 2.6 and 4.4 in two cases. The two lower figures appertain to 20–22 Dynasty glass samples and indicate use of potash-rich materials such as plant ashes. In Mesopotamian, Indian (Ahichchatra, Nalanda, Nasik), as also in Chinese and Japanese specimens, the ratio ranges between 3.5 to 7 in fourteen samples and exceeds 7 in six samples. The small amount of potassium in all Roman glasses including those of the Rhine-province is borne out by the low

percentage values of K_2O and the Na_2O/K_2O ratios, thus disproving Faider-Feytman's, contention that Roman Rhineland glasses contained more potash than soda.[a] The situation is however reversed in medieval France and Germany when the Egyptian source of natron (mainly Na_2CO_3 and $NaHCO_3$ and in some samples, also NaCl, and Na_2SO_4 in appreciable quantities) was cut off and the Frankish and German glass-makers were obliged to depend on plant ashes for alkali requirements. Even then the presence of fairly high percentages of K_2O varying from 2.1 to 5.04 in typical soda-lime glasses of some ancient Egyptian, Assyrian, Indian, Arabian and Central Asian glasses indicates the use of plant ash with natural soda. It should be noted that the extraction of alkalies (potash) from plant ashes for medicinal use was an ancient practice. Elaborate methods of such extraction are given in the *Suśruta Saṃhitā*. Wide variations in total alkalies as also in relative percentages of Na_2O and K_2O are in all probability due to their variations in alkali sources themselves, mineral as well as vegetable.

Large-scale deposits due to the drying up and evaporation of land-locked seas and lakes, leaching out of salts from soils, intentional evaporation of saline water in pits and pans, and plant ashes were some of the natural sources of alkalies available to ancient glass-makers. Sodium salts—carbonates, sulphates, chlorides, etc. (Table X) of dried up lakes at Wadi Natrûn and El Kab in Egypt, Magadi in East Africa, silted up Nile sediments and at other places—were well known in antiquity. Sodium carbonates and bicarbonates from Wadi Natrûn and other places, for example, found their uses as detergents, in medicines and in processes for embalming from early dynastic times. These no doubt provided a readily available source for sodium alkalies for glass-making not only in Egypt but throughout the Near East and the Roman world.

Special importance attaches to chemical analyses of plant ashes from several inland trees and plants and those from coastal regions (Table XI). Analyses of glass samples and plant ashes have fairly confirmed the use of beachwood ashes for the making of glass in Western Europe in the Middle Ages. Geilmann and his co-workers demonstrated that manganese oxides of glasses of this period in Europe were obtained from the high manganese content of the beachwood ashes. Interestingly enough, the ashes of some plants like straw, reeds, chaff etc. contain almost all the ingredients required for glass-making, and it is a reasonable guess that their use as fuels in ancient pottery kilns might have occasionally produced glazes and near-glass materials as a precursor of glass itself.

(c) *Calcium and Magnesium*: Calcium and magnesium are universally present, the former as a major and the latter as a minor constituent. The total CaO.MgO content in 7 Egyptian and Alexandrian glasses selected in these tables ranges between 11.05–15.19 and in 3 samples between 3.04–5.9. For Mesopotamian–Assyrian–Babylonian glass samples, this range lies between 7.17 to 12.12. In Roman glasses which present a more consistent picture, CaO.MgO coverage works out to 7.43 on Caley's averaging and 8.01 on Bezborodov's, although the Carolingian specimen registers 13.20 due to the high percentage of MgO. Wide variations are noticed in Indian specimens,

[a] Faider-Feytman, G., *Revue Belge d'Arcnaoëlogie et d'Histoire de l'Art*, **10**, 1940, 211–30.

TABLE X
Composition of Egyptian Natron
(Compiled from Geilmann *et al.*)

	Ancient samples from 18th Dynasty (after Lucas)				Natural soda				
					Wadı Natrûn				Südl Fessan
	1	2	3	4	5	6	7	8	9
Na_2CO_3	16.1	9.2	94.0	84.7	28.9	75.0	58.6	42.71	39.41
$NaHCO_3$	10.7	6 3	—	—	20.5	5.0	14.3	33 79	44 30
NaCl	25.2	39.3	0.5	1.5	24.8	9.4	7.4	1 83	0 46
Na_2SO_4	27.8	13.2	5.5	13.8	5 8	1.2·	1.3	1.91	0 44
H_2O	8.7	6.8	—	—	12.8	3.7	4.3	16.56	14.80
Insoluble in H_2O	11.5	25.2	—	—	7.2	5.7	14.1	3.19	—

TABLE XI
Chemıcal Composition of Ash Content of Dried Vegetable Materıals and Plants

	Wheat straw	Barley straw	Fern	Reeds	Wheat grain	Beachwood			
	1	2	3	4	5	6	7	8	9
SiO_2	66.2	53.8	6.1	71.4	1.7	5.98	7.8	7.77	12.2
CaO	6.1	7.5	14.1	6.0	3.3	37.65	49.5	41.62	45.8
MgO	2.5	2.5	7.6	1.3	12.4	11.23	14.5	9.98	16.6
Na_2O	2.8	4.6	4.6	0.26	3.3	1.91	3.9	1.57	2.2
K_2O	11.5	21.2	42.8	8.6	31 1	28 26	37.70	23.08	30.5
Fe_2O_3	—	—	—	—	—	1.25	2.7	1.00	1.5
Mn_3O_4	—	—	—	—	—	5 08	12.8	4 23	14.6
P_2O_5	5.4	4 3	9.7	2.1	46.3	6.76	9.6	9.73	12.0
SO_3	2.8	3.6	5.1	2.8	2 2	1.37	3.2	1 26	2.1
S	3.8	2.9	—	—	—	—	—	—	—
Cl	—	—	10.2	—	8.4	0.01	0.1	0 01	0.1

1, 2, 3, 4, 5. *Thorpe's Dictıonary of Applıed Chemistry*, as calculated by Turner (5), 289T.
6, 7, 8, 9. Geilmann *et al.* (after Wolff), 154.

ranging from the lowest value of 2.37 in the Nalanda sample to 13.36 in a bottle-green glass from Nasik. Some specimens from Taxila, Kopia and Arikamedu show a total CaO.MgO content ranging from 2.36 to 9.88. The average of 11 Indian specimens selected in these tables is 7.3%, comparing favourably with that from Roman specimens. Arabian samples record a higher CaO.MgO content ranging from 8.80 to 10.50 comparable with the Mesopotamian–Assyrian–Babylonian figure. Alkaline earth content continued to be high for Central Asian glasses and higher still in potassium-silicate window glasses of medieval France and Germany, in one of which (No. 66, Werla) it registered 29.54 per cent. On the basis of analyses of 330 samples, Sayre noticed that ancient glass before 7th century B.C. was characterized by high concentration of magnesium, that this concentration was reduced in the following centuries and that it again rose in medieval times.[a]

CaO/MgO ratio also varies widely. This ratio lies within 1–2 per cent for 19 samples and 2–5 per cent for 24 samples and is over 5 per cent for 19 samples. Most of the Egyptian, Mesopotamian and Arabian samples chosen have this ratio between 1–2 and 2–5, while for most of the Roman and some of the Far Eastern and medieval European glasses, it has a high value exceeding 5. Matson's[b] attempt to explain CaO/MgO on the basis of the use of dolomite where CaO and MgO are present in almost equal proportions and of calcite with a low MgO content, and his suggestion of an 'international selection from among the available limestones' are not warranted by the analytical data, as has been pointed out by Turner.[c] For a proper understanding of these variations it is necessary to consider the composition of principal raw materials such as sand, natural natron and plant ashes which contain, among others, alkalies and alkaline earths in widely varying proportions.

MINOR CONSTITUENTS

(a) *Alumina*: The range of Al_2O_3 present in ancient and medieval glasses agrees well with the modern range (Table VIII), although high values are also met with. For Egyptian, Mesopotamian and Roman glasses, the value hardly exceeds 3 or 4. For a Roman glass from Mainz, Neumann reported a high value of 7.12%, although Roman values are consistently low (average 2.52–2.88%). Some of the Indian, South East Asian and Japanese specimens are reported to contain high alumina content (Tables III and IV), e.g. Kopia—7.0; Nalanda—6.13; Nasik—5.75; Pasumah, Sumatra—8.95; Oc-eo, Mekong—9.40; and Kofun, Japan—12.04. Turner reports 14.5% Al_2O_3 in an Islamic green glass from Fostat, Egypt.[d] The Orbeti (Georgia) specimen has 8.48%, the Akhsiket 5.78%, Weeze (medieval Germany) 6.12% and a Byzantine/Arabian specimen from a glass weight 8.17%.[e] Aluminium is present in sand and also passes into the glass from the refractory materials of the pot during melting operations.

(b) *Iron oxides*: Ancient glasses contain a higher proportion of Fe_2O_3 as an impurity in sand than do modern soda-lime glasses. Its role in giving rise to a greenish blue colour even when present in minute quantities has been discussed. In the samples

[a] Sayre, 269, 272. [b] Matson (2), 84. [c] Turner (4), 176–77T.
[d] Turner (4), 172T. [e] Turner (4), 179T.

selected, none falls within the range of 0–0.5% and only one sample falls within the range 0.05–0.2. There are ten samples in the range 0.2–0.5; 18 within 0.5–1.0; 25 within 1–2; and 9 samples contain Fe_2O_3 over 2%. Bezborodov's average for Roman glass is 0.81. Indian specimens record values ranging from 1.1 to 5.40% in these tables; values less than 1% are known in specimens from Taxila and Kopia. One Akhsiket (Central Asia) specimen contains 6.10% Fe_2O_3, and still higher percentages, e.g. 9.98% for a black opaque glass from Elephantine Island, Egypt, 8.6% for a dark green Arabian glass and 7.01% for an opaque black glass from Nalanda, are known. Thus none of the ancient glass samples can properly be described as colourless, although in many cases the effect of iron was sought to be neutralized by the use of manganese dioxide as a decolorizer.

(c) *Manganese and Antimony*: The presence of MnO in varying proportions in a large number of samples is therefore not surprising. Out of 72 samples given in our tables, as many as 52 contain manganese in varying proportions. Turner reported manganese in 73 out of 107 analyses given in his tables. Turner has shown that 2% Fe_2O_3 in a 72 SiO_2 . 10 CaO . 17 Na_2O produces a deep green colour, but when such a glass contains 2% Fe_2O_3 plus 3% MnO, it transmits a considerable amount of visible light and looks yellow and transparent.[a] Manganese dioxide and oxide, as stated before, were used for their various colouring effects. The use of 2.13% of MnO in an Egyptian violet glass and 5.01% in an Arikamedu sample deep violet in colour may be noted. In an Akhsiket specimen as much as 22.67% of Mn_2O_3 was used to make an opaque green glass.

Widespread appearance of manganese in ancient glass samples, its variations, its role both as a colorant and decolorant and speculations as to whether its addition was intentional or unintentional as in the case of medieval West European glass due to the use of plant ash,[b] led Smith[c] and Sayre[d] to analyze some 330 ancient glass specimens dating from the second millennium B.C. to the first millennium A.D. Sayre employed combined techniques of quantitative emission spectrography, colorimetry and flame photolysis in Brookhaven National Laboratory, New York, for the determination of 26 elements, with special attention to manganese and antimony. In the first place, concentrations of both manganese and antimony fell into two groups: (*a*) mean value not greatly under 1 per cent, and (*b*) mean value lying around a few hundredths of 1 per cent (Fig. 5). This grouping is more pronounced in clear and colourless glass than in the coloured. The high concentration ranges indicate intentional addition of manganese and antimony as colorants and opacifying agents and as decolorants. The low concentration ranges appear to account for normal impurities.

Some idea as to the role of these two elements as decolorants and preferences in their applications in periods of time and geographical areas can be obtained from Table XII compiled from Sayre's data for clear and colourless glasses. Because of certain differences in patterns, two geographical areas, e.g. the Eastern Mediterranean and the areas from the Euphrates valley to India, have been separately shown. Low concentrations of manganese and antimony in Egyptian and Mesopotamian

[a] Turner (4), 179T. [b] Geilmann and Brückbauer, 456–59.
[c] Smith, 283. [d] Sayre, 263–82.

specimens of the period from the 15th to 7th centuries B.C. are possibly due to impurities and do not indicate their intentional use as decolorants. Examples of clear and colourless glass with low Mn and Sb concentrations did not of course suddenly cease by the 7th century B.C., specimens of such glasses being obtained from later periods (1st to 5th and again 5th to 12th centuries A.D.) from both the geographical areas.

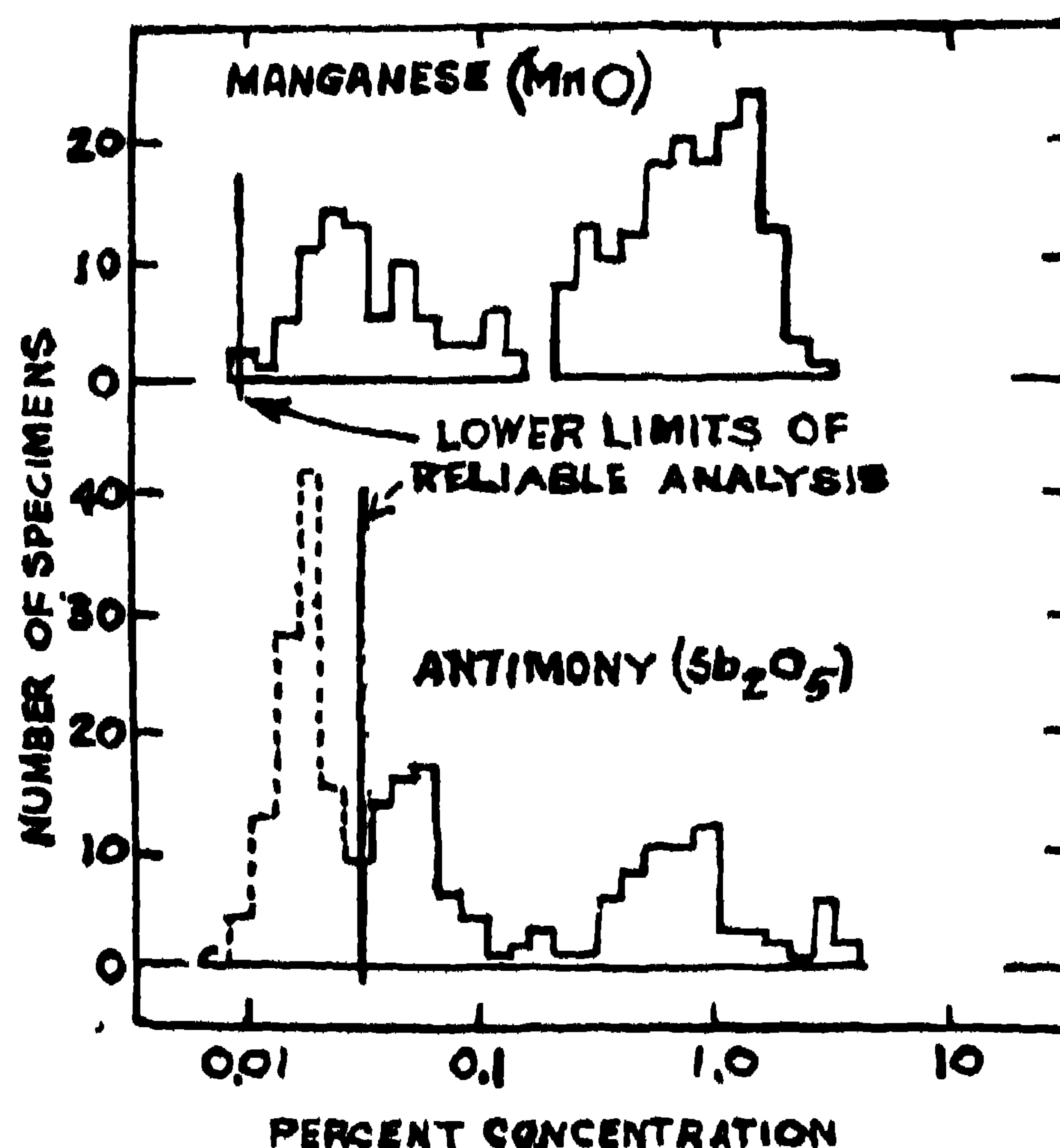


Fig. 5—Manganese and Antimony in colourless ancient glass.

Clear and colourless glass specimens dating from around the 6th and the 7th centuries B.C. and found both in the Eastern Mediterranean areas and those east of the Euphrates valley indicate high concentrations of antimony, varying from 0.53 to 3.2%, whereas manganese continues to remain low, 0.009 to 0.061%. This period is also characterized by significant changes in the glass-making techniques and processes; one such change was a definite shift from a high to low magnesium glass, as noted already. This tendency to use antimony as a decolorant persists well into the Roman period (1st to 5th centuries A.D.) but appears to be replaced by the alternative technique of using manganese in higher concentrations. Thus in the Eastern Mediterranean, while Agora in Athens, Karanis, Anatolia and possibly other centres continued the older praçtice, Roman Syria, Agora later on, Hauran and other centres clearly opted for manganese. The reversion was complete by the 5th century A.D., and during the next 700 years or so manganese remained the acknowledged decolorant in these regions.

East of the Euphrates valley, traditions died hard, and both the methods were practised in different centres. Thus Begram in Afganistan and Roman Dura Europos adhered to antimony in the first few centuries A.D., but Kuyunjik in Nineveh and Brahmanabad in India preferred manganese. In Sasanian times (5th to 7th centuries

TABLE XII

Antimony and Manganese Content of Nearly Colourless and Clear Glass from Eastern Mediterranean Area and from Areas from the Euphrates Valley Eastward

(Adapted from Sayre)

Eastern Mediterranean Area

Period	Provenance	Sample No.	Percentage Sb_2O_5	Percentage MnO
15th to 7th century B.C.	Thebes	781	0.014	0.035
	,,	782	0.042	0.024
	Lisht	814	< 0 027	0.020
	,,	815	< 0.031	0.015
	,,	817	< 0.027	0.020
7th to 1st century B.C.	Phidias	222	2.7	0.024
	Alabastron	669	2.5	0.010
	Phidias	365	2.1	0.061
	Gordion	221	1.59	0.028
	Alabastron	670	0 63	0 020
1st to 5th century A.D.	Athens, Agora	866	0.79	0.045
	Roman Syria	956	< 0.050	4 5
	,,	951	0.051	4.1
	Karanis	633	0.79	0 026
	Anatolia	915	0.41	0.026
	,,	916	0.46	0.68
	Athens, Agora	867	< 0.046	2.4
	,,	868	< 0.030	1.73
	,,	869	< 0.030	1.72
	Hauran	763	0.042	0.85
	,,	767	0.038	0.52
	,,	768	0.060	1.09
	Roman Syria	948	< 0.030	1.74
	,,	949	< 0.030	1.53
	,,	952	< 0.024	1.60
5th to 12th century A.D.	Istanbul, Sardis, Constantinople, Fostat, Islamic cameo vessels	38 samples	0.013 to 0.069	0.24 to 2.1

Areas from the Euphrates Valley Eastward

Period	Provenance	Sample No.	Percentage Sb_2O_5	Percentage MnO
13th century B.C.	Elamite	588	0.015	0.047
	Ziggurat, Tchoga Zanbil	711	0.010	0.11
	Mesopotamia	970	< 0.021	0.031
7th to 1st century B.C.	Persepolis	734	3.2	0.018
	,,	732	2.6	0 019
	,,	733	2 5	0 009
	,,	863	1.31	0.019
	,,	736	0.53	0.016
1st to 5th century A.D.	Begram,	34	1.36	0 020
	Afganistan	28	0.84	0.027
	,,	273	0.81	0.047
	,,	31(1)	0.79	0 028
	,,	22	0.72	0.018
	Kuyunjik,	938	< 0.024	1.59
	Nineveh	939	< 0.030	1.25
	,,	203	< 0.069	1 07
	Brahmanabad,	934	< 0.046	2.1
	India	932	< 0.023	1.31
	,,	935	< 0.023	1.06
	,,	933	< 0.023	0.54
	Dura Europos, Roman	7 samples	0.75 to 0.33	0.017 to 0.26
5th to 7th century A.D.	Sasanian luxury glass	4 samples	2.5 to 0.69	0.19 to 0.026
	Sasanian, Kish	10 samples	0.023 to 0.042	0.12 to 1.33
7th to 12th century A.D.	Raqqa, Nishapur, Susa, Persia	27 samples	0.017 to 0.058	0.20 to 1.07

A.D.), both antimony and manganese were used by glass-makers as indicated by 4 high-antimony and 10 high-manganese glass samples. From the 7th century onward, however, antimony as a decolorant appears to have been completely superseded by manganese, as in the Eastern Mediterranean region.

COLOURING AGENTS AND OPACIFIERS

(a) *Copper*: As a colouring agent, CuO is met with in the majority of the samples. The sealing-wax red in a Nimrud specimen is due to 13.58% Cu_2O whose reduction was facilitated by the presence of 22.80% of lead oxide. A red opaque glass from Taxila contains 7.2% of Cu_2O and 34.85% of PbO. The haematinum glass specimen from the same source contains 5.31% of precipitated copper and 38.93% of PbO. Other examples of sealing-wax red due to Cu_2O and PbO are furnished by Tara Hill, Ireland, and by specimens from Elephantine Island and mosaic plaque and *millefiori* fragments (Table XIII).

(b) *Cobalt*: The use of cobalt, although sparing in antiquity, has been reported by Geilmann for three Egyptian glass specimens of the 18th and 18–20th Dynasty and two Arabian glasses of the medieval period, the percentage of the oxide varying from 0.002 to 0.55. Neumann's analysis of a lapis lázuli glass from Nippur, Mesopotamia gave 0.93 per cent CoO. By spectroscopic analysis, Brill detected 0.002% in an Agora sample of the 2nd century B.C. and 0.01% in another Agora sample of the 4th century A.D. The Japanese glass of the Kofun period revealed 0.003%. Farnsworth and Ritchi proved the use of cobalt in pre-Han Chinese glasses. By the electron beam probe technique, Brill detected 0.13% CoO in a dark blue transparent Alexandrian mosaic plaque and 0.05% in a dark blue opaque plaque of the same source (Table XIII). He also confirmed, by the same technique, the presence of CoO (0.04–0.06%) in two Tell-el-Amarna specimens. These analyses have settled the question of intentional use of cobalt as a colouring agent in pre-Christian times, even from so early a time as the 18th Dynasty. Geilmann's analyses show that glasses containing cobalt also had small amounts of NiO_2 and As_2O_3, pointing to the use of cobalt arsenide.[a]

(c) *Antimony*: Intentional use of antimony, as reported by Sayre, has already been discussed. Geilmann reported the presence of antimony in Egyptian glasses (Nos. 4, 6) and in a Roman glass (No. 24), Turner in glasses from Assyria and Crete (Nos. 15, 16, 20), and Brill in Greek samples from Agora, Athens (Nos. 21, 30) and in a Byzantium sample from Sardis (No. 34). In these samples, the percentage of antimony oxide varies from 0.03 to 0.87 generally, some specimens such as the Nimrud sealing-wax red containing as much as 4.07%. Brill's electron beam microanalysis of an Alexandrian mosaic plaque and a Roman *millefiori* fragment has yielded results shown in Table XIII (percentages of SiO_2, Na_2O, CaO, K_2O, MgO, Al_2O_3 and Fe_2O_3 are omitted).[b]

The most important finding about antimony in relation to ancient glass is its

[a] Geilmann *et al.*, 147–48. 'Das in diesen Glasern das Kobalt begleitende Nickel und Arsen weisen auf die verwendung eines Kibaltaesenides hin.'

[b] Brill and Moll, 147.

TABLE XIII

	Alexandrian mosaic plaque (1st cent. B.C.—1st cent. A.D.)							Roman *millefiori* fragment (1st cent. B.C.—1st cent. A.D.)			
	WO	DBT	DBO	LBO	RO	YO	X	WO	YO	RO	C
Sb_2O_5	8.9	1.3	8.1	5 8	0.8	2.2	1.0	6.0	2.8	1.3	0.8
PbO	0 2	0.1	0.2	0.4	29 0	21.5	0.2	1.6	16.0	4 5	0.0
CuO	0.0	0 3	0.8	3.7	—	0.1	—	0 06	0.28	—	0.02
Cu_2O	—	—	—	—	1 7	—	—	—	—	1.1	—
CoO	0.0	0.13	0 05	0.0	0 0	0.0	—	—	—	—	—
MnO	0.05	0 05	0.05	0.05	0 3	0.05	—	1.3	0 8	1.5	2.7

WO—white opaque; DBT—dark blue transparent; DBO—dark blue opaque; LBO—light blue opaque; RO—red opaque; YO—yellow opaque; C—colourless; transparent; X—hypothetical parent glass; colouring or opacifying agent.

predominant application as an opacifying agent. Until the work of Turner and Rooksby, tin was widely believed to be the opacifying agent used in antiquity.[a] By applying x-ray diffraction methods, Rooksby and Turner studied ancient opal glasses over a period of three thousand and four hundred years, selected from various culture areas (Table XIV). White opalescence was found to be due to the formation of crystals of calcium pyroantimonate, $Ca_2Sb_2O_7$ and other compounds of lime and antimony oxide; opaque yellow due to the crystals of lead pyroantimonate, $Pb_2Sb_2O_7$; opaque turquoise due to a mixture of $Ca_2Sb_2O_7$ and $Na_2O . 2CaO . 3SiO_2$; sealing-wax red due to Cu_2O as already discussed. In 21 specimens of opal (white or near white) glasses of the period from 15th century B.C. to 3rd century A.D., x-ray diffraction detected only two opacifying agents, viz. reduced copper (in sealing-wax red) and calcium and lead pyroantimonates. Leaving aside reduced copper, antimony can be said to be the sole opacifying agent in use during 1700 years from the 18th Dynasty to the 3rd century A.D. Tin oxide as an opalizing agent came to be used from a much later date—11th and 12th centuries A.D. Other opalizing agents also confirmed by x-ray studies, e.g. calcium phosphate, lead oxyarsenate and fluorides, were introduced into the glass technology from the 17th, 18th and 19th centuries respectively.

The dual role of antimony as an opacifying agent and a decolorant calls for an explanation. This must be sought in the valency state of antimony in opal and clear glasses. In the crystals of calcium and lead pyroantimonates, antimony is present in its oxidized pentavalent state. Experimental observations that antimony containing clear glasses become opaque upon oxidation and resist opacification when melted in a reducing atmosphere indicate the existence of antimony in lower valence state in clear glasses. Such different behaviours of antimony in different valence states

[a] Turner and Rooksby (1), 17–28; see also papers by Rooksby.

TABLE XIV

Opacifying Agents Used in Glasses from Ancient to Modern Times as Determined by X-ray Methods

(Compiled from Turner and Rooksby (1), 21–22)

Date and provenance	Colour	Crystalline constituents
1450–1425 B.C., Thebes	White	Mixture of $Ca_2Sb_2O_7$ and $Na_2O.2CaO.3SiO_2$
1450–1425 B.C., Thebes	Blue	$Ca_2Sb_2O_7$
1450–1425 B.C., Thebes	Yellow	Pyrochlore-type substance akin to $Pb_2Sb_2O_7$
1200 B.C., 20th Dynasty	Yellow	$Pb_2Sb_2O_7$
c. 1200 B.C., 20th Dynasty	White	$CaSb_2O_6$
1370 B.C., Tell-el-Amarna	Sealing-wax red	Cu_2O
8th–6th century B.C., Nimrud, Assyria	Greenish blue	$Ca_2Sb_2O_7$
30 B.C. to 100 A.D., Dendereh, Egypt	White	$Ca_2Sb_2O_7$
2nd–3rd century A.D., Begram	Yellow	$Pb_2Sb_2O_7$
11th century A.D., Novgorod, USSR	Bright yellow to orange	$Pb_2Sb_2O_7$–$Pb_2Sn_2O_6$ (one substance)
Late 12th century A.D., Tchernigov, USSR	Pale yellow to ivory	SnO_2
14th century A.D., Islamic	Yellow	$Pb_2Sb_2O_7$–$Pb_2Sn_2O_6$
—Do—	White	Calcium fluophosphate, $3Ca_3(PO_4)_2.CaF_2$
1725–1750 A.D., Venetian	Turquoise blue	SnO_2

controllable during melting operations must have been noticed at a fairly early date, and it is a reasonable guess that glass-makers who had been using this material as an opacifying agent since 15th century B.C. found it convenient at some later date (7th century B.C. ?) to use it as an effective decolorant as well.

(d) *Lead and Barium*: Tables I–VII include 21 glass samples containing lead oxide. Some analyses of coloured glass pieces used in making mosaic and *millefiori* glass are given in Table XIII. In most of these samples, the percentage of PbO is

below 0.5. Turner reported that out of 300 glass objects chemically analysed only 38 showed PbO in excess of 0.5%. Spectrographic analyses, however, detected lead in more samples than did the chemical. Some of the high lead containing specimens included in our tables are Nos. 16 (22.8%), 20 (24.5%), 38 (38.93%), 45 (4.23%), 52 (24.50%). Table XIII records 29% and 4.5% in red opaque and 21.5% and 16.0% in yellow opaque portions of a mosaic plaque and a *millefiori* glass. Turner's tables give 15.33% in a Nippur lapis lazuli blue sample, 43.20% in a Chinese bead, 32.85% in an Irish sealing-wax red and 62.37% in a 17th century white bead from Livland.[a] Exceptionally high percentages of PbO in opaque coloured glasses from 11th century A.D. Novgorod and late 12th century Tchernigov, U.S.S.R.—75.9% (yellow-orange, Novgorod), 72.14% (yellow-green, Tchernigov), 68.17% (yellow or ivory, Tchernigov) —have been reported by Turner and Rooksby.[b]

The pre-Han and Han Chinese specimens containing a high percentage of lead are also characterized by high barium content. Simultaneous presence of lead and barium in a large number of Chinese specimens has been confirmed by spectrographic analyses by Ritchie. Moreover, these pieces contain low percentages of alkalies and no copper oxides. These specimens point to the earliest example of the manufacture of lead-barium glass.

(e) *Dichroism due to Gold and Silver*: Fragment of a Lycurgus glass specimen from Sardis (Table II, 34) exhibits an extraordinary dichroism. It looks pea-soup green or jade-like by the reflected light and a deep magenta by the transmitted light. The chemical composition is that of a typical Roman glass of the period. Brill has shown that the peculiar colour effect is due to the presence of traces of gold and silver in the form of tiny colloidal crystals.[c] It was a very difficult art as evidenced by the rarity of such specimens.

Recent refined techniques and microanalyses have revealed the existence of elements in traces whose importance should not be neglected. These may be present as impurities or might have been added intentionally as we have already seen in our foregoing discussions and may therefore be expected to throw important light on the technology of ancient glass.

Categorization of Ancient Glass

Attempts have been made from time to time at some sort of categorization of ancient glasses. One obvious line has been to examine possible intentional change in the composition favouring the development of glass blowing. Higher silica and alkali content and a low percentage of alkaline earths would be preferable for glass intended for blowing. Post-blown Roman glasses do contain higher percentages of silica and lower percentages of CaO . MgO than do most of dynastic Egyptian specimens, but their alkali contents are lower. The compositions of pre-blown Assyrian glasses, as far as silica, alkalies and lime are concerned, are not markedly different from those of the Roman and would be as good for making blown wares. Some of the Egyptian glasses could also have readily lent themselves to blowing.

[a] Turner (4), 174T. [b] Turner and Rooksby (1), 24. [c] Brill (6), 223·5.

The striking similarities in Roman glasses made in factories scattered over a wide geographical area have been noticed by all reviewers. In Geilmann's view, the differences in chemical compositions of glasses from Egypt and the Near East of the second and the first millennium B.C. and those of the later Islamic types are not very great, and it is possible to conclude the continuation of an almost uninterrupted tradition of glass-making in these areas. He observes: "Die Abweichung der Zusammensetzung der frühen ägyptischen von den arabischen Gläser des 14 Jahrh. n. Chr. sind nicht so gross, dass der Schluss nicht berechtigt wäre, die Rohstoffe der Glasherstellung dürften sich in dem Zeitraum von 3000 Jahren in diesem Gebiet Kaum geändert haben."[a]

Since major constituents have failed to provide any guideline, the minor constituents and elements present in traces have received greater and more searching attention in such attempts at categorization. The analyses for 26 elements of hundreds of ancient glass samples by spectrographic, flame photometric, colorimetric and other techniques, as already referred to, have enabled Sayre and Smith to suggest categorization of ancient glass into the following five broad groups:[b]

I. *Glass group of the second millennium B.C.*—Confined to the period from the 15th to the 7th century B.C., this group is a typical soda-lime glass with high MgO content (4.6–2.9 %), low K_2O (1.89–0.69 %) and traces of oxides Mn (0.046–0.021 %), Sb (0.32–0.011) and Pb (0.0068 %); such glass was produced throughout the Mediterranean area, e.g. Egypt, Mesopotamia, Greece (Mycenae) and Persia (Elam).

II. *Antimony-rich glass group of the period from about 6th century B.C. to about 4th century A.D.*—This group is characterized by lower MgO (1.24–0.60 %), lower K_2O (0.47–0.17 %), consistently high antimony oxide (1.93–0.53 %) and traces of MnO, PbO etc. Specimens of this group have turned up in Greece (Olympia), Asia Minor (Gordion), Persia (Persepolis), Begram and Dura Europos.

III. *Glass group of "Roman" composition*—Confined to the first 5 to 7 centuries A.D., this group is marked by low percentages of MgO (1.47–0.73 %) and K_2O (0.63–0.22), greater percentages of MnO (1.60–0.10) and lower contents of antimony (0.089–0.018 %) and lead. Wide geographical spread of this group has already been discussed.

IV. *Early Islamic group flourishing from the 8th to 10th century A.D.*—This is a typical soda-lime glass with high MgO (6.5–3.6 %) and K_2O (2.2–0.94 %) content, a high proportion of manganese (1.07–0.21 %) and low antimony and lead content. This group appears to be a return to group I with the difference in its high manganese content. This is represented by finds from Nishapur, Susa, Quadrisia, Kish, Raqqa, Fostat and some Iraqi sites.

In the above four groups, the major components—silicon, sodium and calcium oxides—show small variations and overlap for different categories with

[a] Geilmann *et al.*, 148. [b] Sayre and Smith, 1824–26.

standard deviations of the order of 25 per cent according to Sayre and Smith's analyses.

V. *Islamic lead glass group of the 8th to 10th century A.D.*—This group, of which very few specimens have been found, contains a high percentage of lead (40–33 %), low alkali and lime, and lower percentages of MgO, K_2O, MnO and Sb_2O_5. The type is different from the lead-barium glass made in China and also from the lead glass samples found in the U.S.S.R.

In a later report,[a] Smith, on the basis of analytical data of over 300 glass samples, has stated that, while the above-mentioned five compositional groups are still valid, all ancient glasses can be assigned to two general types, viz. (*a*) low magnesia glasses and (*b*) high magnesia glasses. The 'antimony-rich' and 'Roman' groups are typical of the first group with relatively low magnesium concentrations varying from 0.5 to 4 % with mean concentration lying around 1 %. The 'second millennium B.C.' and 'early Islamic' groups contain characteristically high percentages of magnesium varying from 3 to 10 %, with mean concentration lying at 5 %. Thus the mean concentration in the high magnesia type is nearly five times greater than what obtains in the low magnesia type. Moreover, the low magnesia type is also marked with low potassium concentration and the high magnesia type by high potassium content. Here also the difference in the mean values of potassium concentrations is as great.

Smith has further confirmed that despite the vicissitudes of centuries, high concentrations of magnesium and potassium persisted in the compositions of glass in the eastern Mediterranean regions of the Mesopotamian times, of the period between the 1st and the 7th century A.D. and Islamic glass of the 7th to 12th century A.D. 'This similarity of Islamic glass', writes Smith, 'with that of the second millennium B.C., however, has already been noted, and the possibility has been suggested that Islamic glass simply represented a continuation of an ancient glass-making tradition.' Likewise, glass-making in the Rhineland in the Frankish period followed more or less the old compositional tradition of the Roman times in spite of a marked decline in the level of competence. In soda-lime glass, the low percentages of magnesium and potassium characteristic of 'Roman' glasses continued in the Rhenish glass.

In view of the paucity of analytical data, particularly with regard to minor and trace elements, it is difficult to place Indian glass samples under any of these five categories. In Taxila glass, MgO content varies from 0.5 to 2.68 in 8 samples and from 3.74 to 4.5 in 3 samples; K_2O lies below 1 % in 5 samples, but varies from 2.35 to 4.85 in 4 samples. MnO determined for 8 samples lies between 0.01 to 0.34. Percentages of Sb_2O_3 in two samples are 5.08 % and 2.42 %. Some of their pieces might appear to be marked by magnesium and manganese content comparable to those of Group I and II. 5.08 per cent antimony oxide in a white opaque glass and 2.42 % per cent in a turquoise specimen were probably responsible for opal and opaque coloured glass, as was the established practice in these centuries.

[a] Smith, 283–90.

For Kopia specimens, percentages of manganese oxide vary from trace to 0.02 to 0.95 per cent. Antimony percentages have not been given as probably their determination was not attempted; we can assume them, if present, to be less than those of MnO. Magnesia varies from 1.12 to 2.10, the majority lying within 2 per cent. K_2O has not been differentiated from Na_2O. We can label these specimens as low magnesia and low manganese glass, pointing to some of the characteristics of Group I and II.

Arikamedu specimens also contain low magnesia, 0.30 to 2.1 %, higher manganese oxide, 0.14 to 1.99 % (excluding one sample with 5.01 %), but some of them are potash-rich (3.5 to 14.14 %). 0.1 % barium and 0.01 to 0.07 % PbO have been found in some specimens.

Ahichchatra and Nalanda glass specimens generally contain high proportions of magnesia and K_2O comparable to those of Group IV. In one specimen, MnO records 0.06 per cent and PbO 4.23 per cent. It appears that antimony and manganese contents have not been looked for.

That these and other trace elements are likely to show up if latest analytical methods are applied can be reasonably expected from Sayre's results with Brahmanabad specimens (Table XII). The importance of thorough analyses for minor constituents and trace elements by chemical, spectrographic (optical and x-ray), electron-probe, photometric and colorimetric methods of Indian glass samples of ancient and medieval times need hardly be overemphasized.

Furnaces, Manufacturing Techniques and Implements

Details of fire-places, kilns, and furnaces where industrial heating operations used to be carried out in antiquity are lacking or are incomplete and sometimes misleading. Forbes complained of the archaeologists' neglect in these matters and failure to take the help of specialists for proper identification and interpretation.[a] For example, what was once described as a 'smelting furnace' at Gerar by no less an archaeologist than Flinders Petrie turned out, upon expert examination by Wyndham Hulme, to be a 'military forge' for working iron bars.

From modern experiments with making commercial glass out of a mixture of good sand, pure limestone and sodium carbonate in requisite proportions, it is known that decomposition of $CaCO_3$ to CaO and slow chemical reaction of sodium carbonate on sand grains take place below 600°C long before melting starts. At temperatures below 700°C, the solid product of heating remains as a powder and attains a sintered or fritted condition above 750°C. Moderately rapid melting starts at temperatures between 800° to 900°C. In the final processes of melting, the alkali salts dissolve in one another and take on calcium and magnesium carbonates into solution. Decomposition of alkaline earth carbonates and the reaction between alkaline carbonates and sand then proceed rapidly, enabling the lime and magnesia to combine with sand. Chlorides and sulphates which cannot be completely removed during the fritting operations and have limited solubility in molten silicate glass will pass into the final product as analyses for chlorine and sulphur by several workers indicate.[b]

[a] Forbes (VI), 70–71. [b] Turner (5), 294–95T.

The disadvantages of melting the mixture straight away without going through the fritting stage must have been realized at a fairly early date. If the fritting stage is bypassed, the impurities sought to be removed by fritting operations before any melting starts would not only pass into the melt but corrode the refractory materials of the fritting pans; the very handling of the product itself would be rendered difficult. This fritting was done in open pans and the final melting in crucibles of which unmistakable evidence turned up at Tell-el-Amarna excavations by Flinders Petrie. In the remains of the glass factory of the time of Akenhaten (14th century B.C.), Petrie recognized shallow saucer-shaped pans, 10 inches across and 3 inches deep, used for fritting operations, cylindrical pots, 7 inches in diameter and 5 inches deep, and crucibles, about 2 or 3 inches in depth and diameter, for the final melting of the frit.

Nothing definite can be said about the furnaces in use in the early stages of glass-making. From the study of the glass specimens it is fairly certain that these were produced at temperatures not exceeding 1050°C or 1100°C. Wood-fired medieval furnaces dating from the 10th to 16th centuries A.D., of which details are available, were not capable of producing temperatures above 1200°C. Early potters' open hearth and clamp-firing devices easily made available temperatures between 700° to 800°C; domed and closed-type pottery kilns produced temperatures of 1050–1150°C at which Sialk pottery was made.[a] It is therefore reasonable to suppose that the early glass-making furnaces were not very different from those used in pottery and later on in metallurgy. The shape and size of the furnaces, their division into two or three chambers to enable heating by the hot combustion gases out of direct contact with the fuel and annealing processes and other sophisticated designs were doubtless the results of gradual evolution, of which details are imperfectly known. Cuneiform clay tablets containing glass-making recipes of the 7th century B.C. appear to indicate the use of three different types of furnaces in glass factories, viz. furnace for fritting, furnace with a floor or eyes, and arched furnace. Forbes is of the opinion that the origin of the reverberatory furnace, which is a pre-condition for glass-blowing, should be looked for in the glass-making and metallurgical processes obtaining in Mesopotamia about the 7th century B.C.[b]

Some of the techniques used for working with glass include mould-pressing, cane code, core-winding, cold cutting, and various methods of decorating, cutting, painting and enamelling glass to produce objects of great art and beauty which commanded undiminished admiration throughout the centuries. The ancient process of giving shape and design to clay and metal object by pressing these materials into moulds was easily applied to glass in its viscous state, as borne out by several mould-pressed glass objects from the third millennium B.C.

Before glass-blowing, small containers for keeping toilet articles, used to be made by the cane and core techniques. Multi-coloured and patterned rods or canes were prepared by fusing the sections in a mould. Stocks of monochrome canes coloured emerald green, turquoise, cobalt blue, sealing-wax red, yellow, opaque white etc. were prepared. For preparing small vessels, a fugitive core of mud or moist

[a] Forbes (VI), 69. [b] Forbes (V), 139–40.

sand was moulded round a thin circular metal rod. The core was kept in rotation on the marver and the cane was applied to, and picked up by, the core. Zig-zag patterns were developed by using wooden combs and spikes.[a] Techniques of stone-cutters, gem-cutters and seal-cutters, well developed in the fourth and the third millennium B.C., also found their application in working with hard glass blocks, and glass cylinder-seals, ring settings, head-rest (of which the best example is Tutankhamen's) were made by these techniques.[b]

The invention and introduction of glass-blowing, as already mentioned, revolutionized the entire glass industry, and everywhere blown wares rapidly replaced those produced by the older techniques. The glass-blower's pipe and his method of blowing underwent little change over the centuries until machineries were inducted into the trade for mass production of bottles, bulbs for electric lamps and other articles. Harden has observed that in producing finely shaped as well as complicated wares and vessels, the Roman blowers of the first century A.D. and the Islamic workers of the medieval times gave evidence of as much skill and excellence of workmanship as did the Venetian *vitrearii* of the Renaissance.[c]

[a] Thorpe (WA), 467–68. [b] Harden (4), 336. [c] Harden (4), 337.

CHAPTER II

LITERARY AND ARCHAEOLOGICAL EVIDENCE OF GLASS IN ANCIENT INDIA

THE origin of glass in India is still shrouded in mystery. Glass (*kāca*) is mentioned in early Sanskrit and Buddhist literature such as the *Śatapatha Brāhmaṇa* and the *Vinaya Piṭaka*. Its reference has continued in ancient Indian literature of varied types. By the second millennium B.C. the prehistoric peoples of Mohenjo-daro and Harappa were moulding and fusing articles of faience and were glazing beads, pottery and steatite objects with a frit akin to glass. Excavations at Maski in southern Deccan have brought to light glass bangles of the chalcolithic period datable to the first millennium B.C. Specimens of glass bangles have been recovered by excavations at Hastinapur and Rupar at a stratum dated 9th to 8th century B.C. At Taxila, glass beads of 7th century B.C. and of the 5th to 4th century B.C. have been unearthed; and we have several specimens from pre-Mauryan, Mauryan and the Sātavāhana times. By the beginning of the Christian era the use of glass became quite common in India. Glass-making had also attained a high degree of skill and excellence as we know it from Elder Pliny's (75–77 A.D.) reference to the Indian method of manufacturing glass from pounded rock crystal, which he described as 'beyond compare'. In this chapter, we shall examine the literary and archaeological evidence of ancient glass in India.

LITERARY EVIDENCE

In spite of its various meanings in the Sanskrit lexicons, the word *kāca* has been used to denote glass from very early times. The use of this word for glass was common in the daily life during the time of Buddha and thereafter it is found to occur frequently in the Sanskrit and the Pali literature. In the *Yajurveda*[a] (*c.* 1200 B.C.) *kāca* is mentioned as one of the articles of which ornaments for the ladies were made by means of stringing with gold thread. This shows that from very early times the Indians had the knowledge of glass as a material for making ornaments. The word *kāca* mentioned in the *Śatapatha Brāhmaṇa*[b] (*c.* 1000 B.C.) may mean glass beads which were used for the decoration of the horses in the *aśvamedha* sacrifice; so also in the *Taittirīya Brāhmaṇa*[c] (*c.* 1000 B.C.) it is stated that the glass beads of different colours were used for the decoration of horse's manes and tails. The

[a] *KKS.* 3.9.

[b] *evametatyato skandati yasya nivatasya lomāni śīyante yatkācānāvayanti lomānevāsya saṃvaranti hiraṇmayā bhavanti tasyoktaṃ brāhmaṇamekaśatamekaśataṃ kācānāvayati śatāyu vai puruṣa ātmaikaśataṃ ayuṣyevātman protiṣṭhati* / *Śat. Br.* XIII. 2. 6 8.

[c] *yad bāleṣu kācān āvayanti* / *Taitt. Br.* 3. 9. 4. 4–5.

Mahāvagga[a] section of the *Vinaya Piṭaka* alludes to the use of shoes ornamented with glass as forbidden to the Buddhist Bhikṣus; the use of glass bowls was also prohibited for them, as mentioned in the *Cullavagga.*[b] The statement of such prohibition of the use of glass occurs in a religious discourse of Lord Buddha to his disciples, as found in the *Piṭakas.*

In the *Rāmāyaṇa,*[c] the term *kācakāra* (glass-maker) occurs in connection with the description of the citizens of Ayodhyā who followed Bharata for persuading Rāma to abandon his vow of going on exile. The *Mahābhārata* also refers to *kāca* (glass) as produced by the action of fire on a special variety of earth.[d]

Some medical treatises like the *Caraka-* and the *Suśruta-Saṃhitā* prescribe the use of glass vessels for preserving medicines. In the *cikitsāsthāna* of the *Caraka-Saṃhitā*[e] it is stated that in a recipe called *muktādya cūrṇa,* prescribed against cough, glass (salt) appears to be one of the ingredients. Vessels of glass crystal and of cat's eye have been recommended for serving food in the *Suśruta-Saṃhitā.*[f] Glass has also been suggested in the same text serving as a substitute for better surgical instruments. A clear differentiation between *kāca* and *sphatīka* (quartz crystal) has also been made in the same text.

The word *kāca* has been frequently used in the *Arthaśāstra*[g] and the setting of glass fragments (*kṣepaṇa*) in gold ornaments has been mentioned for the preparation of the so-called glass gems. The piercing of glass beads in a molten stage by the jewellers for the purpose of setting ornaments is also found to have been described in the same text.

The *Ācārāṅga Sūtra,*[h] a Jaina canonical text (200 B.C.), also mentions glass as a prohibited article for the Buddhist monks. It is stated that a monk or nun should not accept or use any expensive bowls like those made of gold, silver, glass etc. Mention has been made of the word *kāca* in several works on education written during 100 to 500 A.D.[i]

In the *Divyāvadāna*[j], a Buddhist Sanskrit work of about 200 to 350 A.D., there is also a mention of the word *kāca* in connection with jewels. Varāhamihira in his *Bṛhatsaṃhitā*[k] (505–587 A.D.) has mentioned glass along with other articles as a commodity for trade and commerce. In the *Svapna Vāsavadattā,*[l] a drama of the 6th century A.D., mention has been made of glass coloured like the neck of the peacock.

In a book on the science of jewels, *Ratnaparīkṣā,*[m] the Buddhist scholar Buddhabhaṭa (505–587 A.D.), has made a mention of glass among several gems and jewels.

[a] *na phalikamayā pādukā dharitabbā/na kaṃsamayā pādukā daritabbā/na kācamayā pādukā dharitabbā* / *MV.* v. 8. 3.

[b] *na vaṃśamaya paṭhṭho dhāretabbo / na kācamayo paṭhṭho dhāretabbo/na tipumayo paṭhṭno dhāretabbo* . . / *CV.* v. 9. 1.

[c] *Rām., Ādikāṇḍa,* 90. 27. [d] *MB.* iii. 185. 13. [e] *CS.Ci.* 18. 125. [f] *SS. Sū.* 8. 12.

[g] *AS.* 2, 2.35; 2, 13.44; 2, 13.46; 3, 3.8; 5, 2.23; 7, 17.57.

[h] *Ā. Sū.* 2.1.6.1. *Sū.* 375; *SBE,* 22, I, 166–67.

[i] *HP. ślokas* 42, 45, 68, 73. [j] *DV.* i, 250, 503; ii, 142, 438.

[k] *Bṛh. S.* 42.8; 42.10; 58.23. [l] Ray (PR), 73.

[m] *RPTh.* verses, 46–47; 192–93; 165–66; 205–206.

Glass is mentioned in the *Garuḍa Purāṇa*.[a] A reference to a coloured (green) glass is found in the *Agastimata*, a 6th century A.D. work by Agasta.[b] Amara Siṃha in his *Amarakośa*[c] (7th century A.D.), a well-known Sanskrit lexicon, has mentioned several glass articles like *siṅghāṇa* (a glass vessel), *śikyakāca* (glass cup) and *kācasthāli* (glass dish). In the *Kuṭṭanimata*,[d] a work on the life of prostitutes by Dāmodara (719–813 A.D.), there is a mention of garlands of glass jewels. Glass is also mentioned in the *Kāmaṇdakīya Nītisāra*[e] (700–750 A.D.), *Gauḍavaho*[f] (729–753 A.D.), *Bhallaṭa Śataka*[g] (883–902 A.D.), *Kathāsaritsāgara*[h] (1063–1081 A.D.), *Yuktikalpataru*[i] (1075 A.D.) and *Śukranītisāra*[j] (12th century A.D.).

The use of glass as vessels and utensils is found in many medical works, alchemical texts,[k] treatises on jewels,[l] Sanskrit lexicons[m] etc. The use of spectacles is found in a Sanskrit text entitled *Vyāsayogicarita*,[n] (a biography of Vyāsarāja, the great Mādhava pontiff of 1446–1539 A.D.) by Somnath Kavi, a contemporary of Vyāsarāja.

The foregoing literary references indicate that glass was possibly known in the Vedic age in the form of beads in the time of the *Śatapatha Brāhmaṇa* and of bowls in that of the *Cullavagga*. The *Svapna-Vāsavadattā*, *Agastimata* and the *Garuḍa Purāṇa* bear testimony to the existence of coloured glass in the 6th–7th century A.D.

Evidence from Archaeological Source

Archaeological excavations provide more or less definite information regarding the knowledge of glass and glass-making in ancient and medieval India. It helps to determine the period in which the excavated specimens were fabricated from the position of the stratum in which these were found. Coins associated with many excavated specimens of glass wares also furnish another source of dating the latter. In some cases where the specimens were associated with carbonaceous matter, radiocarbon dating has provided a very important means. These methods have established that glass and glass-making were known in India as early as the chalcolithic period. We shall attempt here a brief description of glass specimens of different types, e.g. beads, bangles, and miscellaneous objects, their colours, shapes and datings. These specimens were recovered from about forty different excavated sites.

ADAMGARH

The excavation was made at Adamgarh[o] hill and rock shelter in the district of Hoshangabad on the southern bank of the Narmada. The area contains altogether eighteen trenches (ADG-1 to ADG-18). The rock shelters are renowned for their paintings and for the occurrence of wares of palaeolithic and microlithic period. A few

[a] *Gd. P.* 73. 9–10. [b] *AM.* verse 301. [c] *Amara.* 2, 9. 98; 99; 10, 30; 3, 3. 28.
[d] *KM.* verse 166, 694. [e] *KNS.* II. 71. [f] *GV.* verse 917. [g] *BŚ. guccha* IV.
[h] *KSS.* 24, 179; 22, 216. [i] *YK.* p. 78. [j] *ŚN.* iv. iii. 191. [k] Gode (2), 147.160.
[l] *NRP.* verse 180, 182. [m] *ACK.* 51, 145; *HK.* 4, 758; *Trik.S.* 63.
[n] *VC.* cxx; 72; also Gode (3), 102–12. [o] *IAR* (1960–61), 13.

pieces of glass and glass bangles have been recovered from the two top layers of all these trenches.

AHAR, AHAD[a]

This area is situated on the river of the same name about 2 miles to the east of Udaipur town, and about half a mile west of Udaipur railway station. It is a part of Udaipur. Glass objects,[b] discovered from Ahar, are beads and bangles. Out of five beads, two are of plain translucent variety, two of tabular cuprous glass (Period II—3rd century B.C.) and the fifth is of opaque green colour. The first two show pulled bubbles and have a very rough surface. They are short tabular, barrel and globular. Four pieces of glass bangles have been discovered. All of them are of monochrome category. Of the four pieces, two came from the phase Ic (Period II) and two were of surface collection. These bangles are of two types—those belonging to phase Ic are plano-convex, and those of surface collections show triangular section. The colour of these glass bangles varies from turquoise blue, sea-green to milky-white. All these bangles are found to be translucent and full of bubbles. The technique employed for making these bangles was rather crude as indicated by the uneven thickness. Due to the leaching out of the alkalis, the bangle pieces are covered with a whitish filmy patina.

AHICCHATRA

Ahicchatra, the ancient capital of the Northern Pāñcālas according to the *Mahābhārata*, is situated about seven miles to the north of Aonla, a subdivisional town in the district of Barielly and is about half a mile to the north-east of the village of Ramnagar.[c] In the year 1940–41 the excavation at Ahicchatra was carried out by the Archaeological Survey of India. The glass objects that have been unearthed at Ahicchatra are mainly of bead material, distributed practically among all the strata. Their datings extend from *c.* 300 B.C. to 1100 A.D. More than one hundred glass beads were recovered from excavations, besides several others from the string of surface collections. The shape of these beads is generally spherical, oblate, hexagonal, barrel, cylinder and flattened, cornerless cubes, circular, lenticular with lug-collars, curved pendant, a double-chambered cylinder, square in section, lenticular, etc. An account of the classification of these beads, specially according to their colour along with their shape, the method of preparation and their distribution in different strata is given here.

Green beads. The colour of the glass green beads[d] (twenty-eight in number) ranges in shades from the bright leaf to dull green and differs in the degree of opacity. Of these, twelve are transparent and the rest opaque. The colouring agent appears to be copper in most of the cases, but three or four seem to be coloured with iron. A thin film of salts is visible on several transparent beads and a simple immersion test in pure water often proved to be useful for the identification of the original colour.

Various methods were employed for their preparation—(i) wire-winding process,

[a] Sankalia, Deo and Ansari, 1. [b] Sankalia, Deo and Ansari, 165, 204.
[c] Cunningham, 255 ff. [d] Dikshit (4), 55.

(ii) moulding, (iii) from thread, and (iv) by folding. Most of the beads are made by the first process. These beads are generally distributed in all strata excepting stratum IV (100–350 A.D.). Their shapes have already been described above.

Blue-green beads. There are twelve beads of blue-green[a] glass, resembling the persian blue shade. Three of them are stratified and are derived from strata IVc and I (100–350 and 850–1100 A.D.).

The above-mentioned beads were prepared from cane-glass wound on a spoke and in several cases flattened to form a lenticular shape when the glass was plastic.

Blue beads. There are thirty-three blue glass beads,[b] of which a very large percentage has a very deep blue shade and the others pale. The colouring agent of the former is cobalt or copper. Nine of these blue-coloured beads show a very bright turquoise shade. There are two very old specimens of blue glass, the colour of which cannot be matched on account of their iridescent surface. The glass of these beads is generally of a very good quality.

These beads are moulded and only in a few cases there are instances of cane-glass. The most popular shape is spherical and oblate. Besides these usual shapes, there can be found other varieties, e.g. short cylinder, barrel shape with a lenticular section and lug-collars.

Blue millefiori beads. Among the beads of this site the most interesting one is a small barrel lenticular bead with lug-collars, having a millefiori[c] pattern on it. It is a folded bead having a blue core and the decoration consists of several vertical hatchings in red, white and black in a double black border. The pattern is laid slantingly across the body of the bead. Though these types of beads have a wide distribution in the Gangetic valley, yet their stratification is not very clear.

Orange beads. These beads, only seven in number, are short barrel annular in shape and are opaque.[d] They are distributed in strata IV and III extending over the period of 100 to 750 A.D. Their colour, as indicated by microscopic examination, is due to fine particles of cuprous oxides in suspension and the dull opaque appearance of these beads arises obviously from their devitrification.[e]

Red beads. Red beads[f] are mainly of two varieties: opaque dark red and bright red. Dark red opaque glass beads (five in number) are distributed in strata VII to II extending over the period of 200 B.C. to 1100 A.D. All of them are made from long canes and are fire-polished, except one which is moulded. They are the usual cylindrical oblate beads and represent a common shade of copper-red glass. They have wide distribution throughout India.

A larger number of beads of bright red type have been recovered from this site. Of these one specimen is opaque and has the colour of *guñja* berry-seed. The red colour is due to copper as the main colouring agent.[g]

Red beads with white core. One of these red beads[h] from surface collection is described as having a cylindrical tube shape with a white porcelainous matrix, over which a transparent red-coloured glass is coated.

Gold-foil beads. They are only eight in number. In this special type of glass beads,

[a] Dikshit (4), 56. [b] Dikshit (4), 57. [c] Dikshit (4), 57. [d] Dikshit (4), 57.
[e] Dikshit (4), 57. [f] Dikshit (4), 58–60. [g] Dikshit (4), 59. [h] Dikshit (4), 57.

a layer of gold foil is pressed on a glass matrix when hot and is covered with another coating of transparent glass. One most interesting find of the present collection is a row of four segmented beads which have not been separated for being made into individual ones.[a]

Most of the beads are unusually large spherical or standard barrel shape and show a collar-like effect at the edges where they are separated by notches made in the long cylindrical tubes out of which they are prepared.

Black beads. Of the fifteen specimens of the black type,[b] nine were recovered from stratified deposit. They are of the common spherical and barrel circular varieties except one which has a bicone pentagonal shape. Its original shape has disappeared due to corrosion.

Black and white beads. Among the glass specimens of Ahicchatra six beads of black and white type[c] have been recovered in which a composite glass was used. This was made by two processes (vide Chapter IV).

AHMEDNAGAR

A recent discovery (in June 1965) of eight glass flasks in association with thirteen Chinese porcelain bowls at Ahmednagar city,[d] in Maharashtra state, ushers in a new chapter in the history of glass. It is for the first time that such large and well-dated flasks have been found in this country. From the descriptive label and inscriptions attached to these Chinese bowls it could be asserted that these were of Chinese origin and of the Ming dynasty, and as these eight flasks are associated with them, they may also be attributed to the same period. It might be noted in this connection that during this time there was a good trade connection with China, which is clearly proved from literary evidence (vide Chapter V). The description of these eight flasks is given below: they are flattened on the sides with a semi-circular or round body and tall cylindrical neck; their height ranges between 27 to 34 cm; they have an *omphalos* or depressed kick in the base and a beaded rim at the top; the bases vary from 12 to 14 cm in their width and the longest tapering neck in one instance is about 24 cm. They are of green and greenish blue colour.

ALAGARAI

The excavation at Alagarai,[e] located on the northern bank of the river Kaveri (about 45 km to the west of Tiruchchirapalli in Taluk Musiri) was conducted by the Department of Ancient History and Archaeology. Glass specimens have been recovered from period I and II of the excavated site. Findings of period I are beads of shells and glass, shell bangles, terracotta beads and ear-ornament. That period II is essentially a continuation of period I is revealed by new innovations in the shape of glass, paste, beads, bangles of glass, etc.

ALAMGIRPUR

The excavated site at Alamgirpur,[f] 17 miles west of Meerut and 28 miles north-

[a] Dikshit (4), 57–58. [b] Dikshit (4), 60. [c] Dikshit (4), 60–61.
[d] Dikshit (9), 74. [e] *IAR* (1963–64), 20–21. [f] *IAR* (1958–59), 50–55.

EARLY HISTORICAL SITES

IN MANY OF WHICH GLASS OBJECTS HAVE BEEN FOUND

SCALE OF MILES

100 50 0 100 200 300 400 500

68°E
72°E
76°E
32°N
28°N
20°N
16°N
12°N
76°E
84°E

SAR DHERI
TAKHT-I-BAHI
SHAHJI-KI-DHERI
SAHRI-BAHLOL
JAMALGARHI
CHARSADA
TAXILA
MANIKYALA
TOR-DHERAI
R. RAVI
R. SUTLEJ
SUNET
RUPAR
JAGATGRAM
KURUKSHETRA
THEH POLAR
RANGMAHAL
SIRSA
AGROHA
RER
HISSAR
HANSI
R. INDUS
HASTINAPURA
KHOKRAKOT
TOSHAM
DELHI
AHICHCHHATRA
KAMPIL
BAIRAT
MATHURA
PIPRAWA
RUMMINDEI
SAHETH-MAHETH
SAMBHAR
R. GANGA
R. YAMUNA
RAIRH
LAURIYA-NANDANGARH
KASIA
BASARH
GAUHATI
BANGARH
BRAHMANABAD
MIRPUR KHAS
R. LUNI
PAWAYA
NAGARI
PAHARPUR
PATNA
MAHASTHANGARH
SARNATH
BHITA
MANDASOR
KAUSAMBI
RAJGHAT
NALANDA
RAJGIR
BODHGAYA
MAINAMATI
BESNAGAR
BHARHUT
UJJAIN
SANCHI
LALMAI HILLS
TRIPURI
BARODA
MAHESVAR
TAMLUK
MOTA MACHIALA
AMRELI
R. TAPTI
R. MAHANADI
NAGPUR
BAHAL
SISUPALGARH
NASIK
BOMBAY
SALIHUNDAM
R. GODAVARI
KONDAPUR
HYDERABAD
BRAHMAPURI
JAGGAYYAPETA
NAGARJUNAKONDA
AMARAVATI
PAKHLIHAL
MASKI
HAMPI
BAY OF BENGAL
ARABIAN SEA
BRAHMAGIRI
CHANDRAVALLI
MADRAS
ARIKAMEDU
SENGAMEDU

- ANCIENT SITES
- ANCIENT SITES -WITH NBP WARE
- MODERN CITIES

A Map showing archaeological sites in which glass objects were found.
(Based on Y. D. Sharma, *Ancient India*, No. 9, 1953, p. 118)

east of Delhi, revealed four cultural periods; the earliest belongs to the Harappan culture. Period II of the site shows the occurrence of the Painted Grey Ware and black-slipped, black-and-red and plain red wares. Among other finds of this period mention may be made of vitreous paste and beads of glass. The dating of period II may be regarded as representing a late phase of the Painted Grey Ware culture, which is supported by the occurrence of iron throughout all the levels of the period.

AMRELI

Amreli[a] (Lat. 20°31′ N., Long. 71°31′ E.) is situated in Saurashtra, a part of the Gujarat State. The glass specimens that have been recovered from this site are loop-handles of a bowl or a cup, fragments of rims of two bowls—one sub-triangular in shape. They are pinkish, opaque and dull opaque white glass.

ANTICHAK

The University of Patna carried out an excavation at Antichak[b] in the district of Bhagalpur during the years 1960–62. Three stages of occupation were observed at this site. From the second phase were recovered a few pieces of green glass along with terracotta beads of various shapes, seals, sealings and inscribed sherds etc. This phase can reasonably be dated from the thirteenth to the fifteenth century A.D.

ARIKAMEDU

Arikamedu, an ancient Indo-Roman trading station, situated near Pondicherry on the tropical Coromandel coast,[c] is a site where excavation was conducted by the Archaeological Survey of India during the months of April to June in 1945. Its stratigraphical evidence may be divided into two sectors—northern and southern; the northern sector is again sub-divided into (i) Pre-Arretine, (ii) Arretine and (iii) Post-Arretine, extending from the end of the 1st century B.C. to the mid or late 1st century A.D. The southern sector is also sub-divided into (i) Pre-structural, (ii) Early phase, (iii) Main Drain period, (iv) Late Drain period and (v) Latest phase extending from before the middle of the 1st century A.D. to the second century A.D. or later. The datings of the layers are mainly based on the processes of evolution and devolution of potteries (i.e. their colour, shape and their fabric) of these northern and southern sectors and almost all these layers contain the glass specimens.[d] More than two hundred beads of various materials were found in the excavations. Of these, the majority of beads are made of glass.[e] Their range of colour is limited; shades of blue and green are the most popular colours throughout, followed by copper-red; less common colours are white, black, yellow, violet and brown; grey is rarely found. The materials are generally opaque but sometimes translucent and transparent glass are also found.

The range of the shapes of the beads is rather limited. The main shapes are spherical, spheroid, pear-shaped, cylindrical, barrel, truncated bicone, oblate and collared. Some of them may be divided into sub-types, such as circular, square,

[a] Rao, 80–81. [b] *IAR* (1961–62), 3–4. [c] Wheeler, Ghosh and Krishna Deva, 17.
[d] Wheeler, Ghosh and Krishna Deva, 50. [e] Wheeler, Ghosh and Krishna Deva, 98, FN 5.

hexagonal etc. according to their cross-sections. A few very tiny glass beads spherical or spheroid in shape have been found throughout all periods. The three smallest ones are .05, .06 and .08 inch respectively. Some beads, mis-shaped in manufacture, have also been recovered from the later strata in the southern sector. The existence of these along with a number of unfinished ones of various materials and some fragments of semi-precious stones seems to suggest that beads were manufactured on a large scale at Arikamedu. A frog-bead of light green glass has been mentioned in the *Pondicherry Bibliothèque*, which was also found at Kausambi and Taxila.

Besides beads, other specimens of the site are fragments of pillar-moulded bowls of whitish iridescent glass, bowls of blue glass, a bangle and a large number of glass rods. Fragments of four or five pillar-moulded bowls of whitish iridescent glass were found at Arikamedu by the French excavators. These types of bowls originated first in Italy and spread throughout the Roman world from the end of the 1st century B.C. to the end of 1st century A.D. They were also found to occur at Haltern (11 B.C.–16 A.D.) and Hofheim (40–51 A.D.) in Germany.

In the northern sector of the pre-Arretine layer of the site was found a fragment of a bowl[a] of blue glass of Mediterranean origin with horizontally ribbed sides.

Bangle. A fragment of a bangle[b] of amber-coloured glass with lozenge-shaped impression alternately filled with dots and an oblique line forms the only glass bangle specimen during the year of excavation in 1945. It was recovered from the northern sector of the post-Arretine layer. There are fragments of two other glass bangles discovered by earlier excavators, as has been recorded in the *Pondicherry Bibliothèque*.

Glass-rods. Several rods of glass-like material (*c*. 1st–2nd century A.D.), unearthed at Arikamedu, were sent to Dr. B. B. Lal by the Government of Madras for analysis of the composition of the raw material, because these rods looked very much like fossil-wood.[c] But after physical, chemical and microscopical examination it has been concluded by Dr. Lal that they are composed of glass, and various metallic oxides have been used for producing different colours.

These rods are of various colours—olive-green, bottle-green, cobalt-blue, greenish blue, brick- and liver-red. Most of them are opaque and a few are transparent. A whitish film on the surface of some of the specimens is due to their prolonged burial in the soil.

Most of these rods range from 2 cm to 2.4 cm in length and a few specimens are of larger dimensions; the longest is 4.6 cm. The fine threading holes in some of them suggest that they were perhaps used for the preparation of perforated beads, while others are solid without any holes. A core of sand is found in several rods.

AZAMGARH AND OTHER SITES

Explorations in the districts of Azamgarh, Allahabad, Faizabad, Ghazipur and Varanasi were carried out by the Varanasi Hindu University. Glass objects[d] in association with the Northern Black Pottery, grey, black and red-and-black slipped wares were found in these sites, situated on the bank of the Ganges.

[a] Wheeler, Ghosh and Krishna Deva, 102. [b] Wheeler, Ghosh and Krishna Deva, 108.
[c] Lal (Dr) (3), 139. [d] *IAR* (1961–62), 53.

BAGOR

The village of Bagor lies on the left bank of the Kothari river, about 25 km to the west of the town of Bilwara. A short-term excavation was carried out at the microlithic site of Bagor, which at its later phase yielded beads of semi-precious stones and glass.[a]

BHITA

Excavations at Bhita[b] by Marshall in 1911 led to the recovery of glass objects (belonging to 1st–3rd century A.D.) of various colours—blue, azure blue, deep blue, black, green with gold leaf, etc.

BRAHMAGIRI AND CHANDRAVALLI

These two sites in the Chitaldrug district of Northern Mysore[c] show distinctive elements of the Arikamedu culture. A clear succession of three main cultures has been determined here: I. Brahmagiri Stone Axe Culture (1st millennium B.C. to the beginning of 2nd century B.C.); II. Megalithic Culture (2nd century B.C. to the middle of the 1st century A.D.); III. Andhra Culture (middle of the 1st century to the third century A.D.).[d] The excavation was carried out (in March, April and May 1947) by the Archaeological Survey of India in collaboration with the Archaeological Department of Mysore state. In the Andhra level abundance of glass[e] is noticeable and the glass objects are mainly bangles and beads.

The colours of the glass bangles are black, stratified glass (a strip of yellow and grey), sky-blue, light green, etc. and they are plano-convex and triangular in section.

Glass beads are five in number and all have been discovered from the Andhra level. Their shapes are short barrel-circular, short oblate-circular, spheroid and long-barrel-groove. Colours are deep and light green translucent, green opaque, sky-blue (opaque), deep green (opaque).

BRAHMANABAD

The specimen of a complete glass bowl from Brahmanabad[f] in Sind constitutes an important landmark in the history of glass in this region. It was found by Cousen in his excavations in 1908–9. The bowl is attributed to about 400 A.D. It has a globular belly with vertical ribbings all over the body and a short neck having an out-turned rim. It was covered with an iridescent patina when recovered. The patina has now peeled off and the thin walls of the bowl appear to be highly transparent having a pale greenish blue tinge. It is not free from air bubbles and appears to have been blown in a mould. It is now preserved in the Prince of Wales Museum. From the varied character of other associated objects found at Brahmanabad, it is very difficult to ascertain whether it is of Indian origin or not.

BRAHMAPURI (KOLHAPUR)

It is an elevated place on the western outskirts of the city of Kolhapur (N.

[a] *IAR* (1967–68), 41–42. [b] *ASI/AR* (1911–12), 29, 94. [c] Wheeler, 200–203.
[d] Wheeler, 202. [e] Wheeler, 263, 265. [f] *ASI/AR* (1908–1909), 82.

latitude 16°41′, E. longitude 74°71′). It lies on the right bank of the Panchganga River.[a] Four different layers have been studied on the basis of the pottery. These are: (i) Brahmani, (ii) Late Sātavāhana, (iii) Sātavāhana and (iv) Pre-Sātavāhana. Glass objects occurred uniformly in all the layers of the site. They are mostly beads, bangles, rings, etc.

Beads. Varieties of colours like blue, different shades of green, yellow, copper-red, black, etc. were used. A very wide range of shapes is to be noticed in them—spheroid, cylindrical barrel, oblate hexagonal, biconal, disc, fluted, biconical, etc. In most cases they were made by wire-wind, moulded and cane processes.[b]

Bangles. One hundred pieces of glass bangles[c] (monochrome and polychrome) were recovered from the third and the fourth layers and are classified into different types according to their colour, shape, technique and design.

Thin monochrome types are usually round on the circumference and are black, yellow, green, brown, dark green, dark or navy blue coloured with various shades.

Thick monochrome types are of various shapes such as (i) round (light or greenish blue) and semi-round, (ii) flat (thick monochrome) with brown colour, (iii) round or flat with a raised central ridge, (iv) broad with concentric rings and beaded circumference and (v) thick with grooves on the circumference.

Thin or very thin monochrome body with appliqué design.

Monochrome body incised on the face with cross and vertical strokes.

Round monochrome body with close oblique grooves.

Facetted monochrome body.

Thick types of bangles have (a) thick, rounded, convex body with fused bands in two colours with alternating twists, (b) thick convex body with raised top and side grooves in oblique twists.

Another type has semi-thick rounded body with elongated yellow and white ovates on black body. One bangle of transparent glass of fine light blue colour[d] (*c.* 100 B.C.–200 A.D.) has been analysed by Dr. B. B. Lal. This was moulded with a diamond-shaped design and its colouring agent was copper.

Besides these monochrome types there are also polychrome types with green or brown, yellow-brown, yellow and green, bluish green with green and yellow patches. There are a number of ordinary soda-lime glasses with different colours. The various coloured glasses were superimposed one over the other and the line of demarcation was clearly seen in the enlarged cross-section.

Rings. Like the bangles, finger rings[e] are also of various types, according to the colour and designs of manufacture—(i) simple monochrome, (ii) simple monochrome but with corrugated circumference, (iii) polychrome and (iv) lustrous. Their colours are black, yellow, pale brown, bluish green, light green. In this connection it is interesting to note that the glass obtained at Kolhapur is of very good quality and is generally very well preserved. The presence of much glass slag and the number of unfinished beads at various stages of manufacture show that there was a flourishing bead-making industry at Kolhapur. Besides, a huge quantity of glass bangles, com-

[a] Sankalia and Dikshit, 9. [b] Sankalia and Dikshit, 98. [c] Sankalia and Dikshit, 116–17.
[d] Lal (Dr) (2), 51. [e] Sankalia and Dikshit, 118–20.

plete, incomplete and fragmentary types, also suggest the presence of a glass bangle industry,[a] perhaps on the mound where the excavation was conducted. In addition, a good quantity of glass wares, glass slag, ashes mixed with lime and parts of a kiln were found in different parts of the excavated areas.

BROACH

The town-mound at Broach,[b] the ancient Bhārukachha of Indian literature and Barygaza of the classical geographers, was excavated by the Western circle of the Department of the Archaeological Survey of India. The occupation of the site may be divided into three periods. Period I (belonging to 3rd century B.C.) yielded glass beads in association with the beads of semi-precious stones, agate chert, chalcedony and jasper. Periods II and III revealed only the occurrence of pottery wares.

CHANDRAKETUGARH

At Chandraketugarh[c] the work of excavation was carried out from 1957 both at *Khanamihirer dhipi,* to the north of Calcutta–Basirhat road and at the paddy field known as Itkhola to the west of the Bera-Champa-Hoard road. The occupation of the site may be divided into seven periods, beginning from the Mauryan age to the post-Gupta period. Of these, period IV (probably assignable to the Sunga-Kushana age) yielded beads of glass and stones including chalcedony, dice of bone, shell bangles, etc.

DEVNIMORI

It is situated in the district of Sabarkanth, Gujarat. It holds the remains of a large Buddhist establishment, which is the main area for excavation. In the construction of the Vihara three main phases were noted: the earliest dating to *c.* 200 A.D., the second not earlier than 300 A.D. and the third ascribable to 600–1000 A.D. Among the findings mention may be made of a circular casket containing two silk bags, a small gold bottle, pieces of wood and the fragments of hollow cylindrical objects of blue glass[d] in association with silver coins of the Ksatrapa period. Besides, fragments of the neck of a bottle of deep blue colour (the colouring agent being copper), of which the largest piece is about 1″ in length, about $\frac{1}{2}$″ in height and about $\frac{1}{10}$″ in thickness, a fine petal-shaped flat glass partially devitrified, with a very rough surface, and a rim of a bowl of clear transparent glass of 3rd to 5th century A.D. have also been recovered.[e]

DHARANIKOTA

The excavation at Dharanikota in the district of Guntur was carried out by the South-Eastern circle under Sri M. Venkataramayya. Among its seven structural phases, glass objects[f] of varying shapes and colours have appeared in phase II (*c.* 1st century B.C.). Mention may also be made of an assortment of glass objects from the

[a] Sankalia and Dikshit, 98, 116–17. [b] *IAR* (1959–60), 19. [c] *IAR* (1959–60), 50–52.
[d] *IAR* (1962–63), 8. [e] *IAR* (1962–63), 8; Mehta and Chaudhari, pl. xxix. A. B, C.
[f] *IAR* (1962–63), 2; *IAR* (1963–64), 2.

deposit in association with sherds of the rouletted and the Northern Black polished ware.

ERAN

Eran (ancient Airikina) is situated in the district of Sagar. Three mounds, namely ERN-I to ERN-3, were under operation and the excavation was carried out by the University of Saugor. The stratigraphy of the site from bottom upwards covers the following periods: period I (chalcolithic phase)—relating to the 2nd half of the second millennium B.C.; period II—covering some centuries prior to the Christian era; period III—extending from the 1st century to the 5th century of the Christian era, and period IV—covering 16th to 18th century A.D. Periods III and IV are found to be rich in glass beads and glass bangles[a] respectively.

HASTINAPUR

Hastinapur (29°9′ north latitude and 78°3′ east longitude) is located in Mawana Tehsil of Meerut district in Uttar Pradesh (formerly United Provinces). Exploration at this site was carried out by the Archaeological Survey of India. The occupation of this site may be divided into five phases: phase I—covering a period prior to 1200 B.C.; phase II—relating to the period *c.* 1100–800 B.C.; phase III—extending over a period from the early 6th to the early 3rd century B.C.; phase IV—covering a period from the early 2nd century B.C. to the end of the 3rd century A.D., and phase V—from the late 11th to the early 15th century A.D. The excavation yielded eighteen glass beads (ten are fragmentary) which were found throughout all the periods excepting period I. Their colour varies from black to deep blue and green. Of the four opaque beads, the spherical ones are etched. Others are long or short cylinder and circular.[b]

Glass bangles are the largest in number and are recovered from various levels, mostly from the phase V. They are generally opaque, and some are translucent. They are brown, black and green in colour with rectangular, circular, double convex, oblong and triangular sections. The occurrence of glass bangles from period II (1100–800 B.C.) is noteworthy because of their antiquity and because of the fact that the evidence of the use of glass bangles at so early a period is not elsewhere available.[c] This contradicts the view of some scholars that glass bangles came into use in India only during the medieval period.[d] The chemical analyses of these two specimens of glass bangles have been made by B. B. Lal, Archaeological Chemist.

The first specimen is brownish glass having an ordinary soda-lime silicate structure with a very low percentage of iron. Its hardness lies between 5 and 6 and the specific gravity is 2.55. Its softness is due to the presence of a very low percentage of aluminium silica, which was highly suitable for the manufacture of bangles. The second specimen is a black-coloured bangle with a clear conchoidal fracture of typical glass. It has a hardness of about 6 with specific gravity 2.56. It also contains a very low proportion of aluminium and silica. The dark colour of the bangle is due to the presence of iron. Sodium is present in large quantities whereas traces of phos-

[a] *IAR* (1960–61), 17–18; (1961–62), 24–25; (1962–63), 11–12. [b] Lal, 8, 28, 92–93.
[c] Lal, 90. [d] Sankalia (1), 252 ff.

phate and potassium have been detected. The specimen is thus a soft glass of soda-lime type. The present condition of both the specimens (i.e. their freshness, unmarred by weathering and decomposition) indicates that after fabrication the bangles were perhaps subjected to careful annealing.[a]

HEMMIGE

The excavation at Hemmige on the right bank of the river Kaveri was conducted by the Department of Archaeology, Government of Mysore. The site yielded glass beads and glass bangles.[b]

KANCIPURAM

The excavation of the deep deposits of Kancipuram in the district of Chingleput reveals two cultural periods with sub-divisions in period I. Glass beads and glass bangles[c] have been recovered from period II (i.e. the medieval period) in association with the thick dull red pottery.

KARAD

An extremely limited extent of excavation was made at Karad[d] (a place in the Deccan) and the glass specimens, recovered from the site of its Sātavāhana level, are beads of blue glass with lug-collars, gold-foil beads, etc.

KAUNDINYAPURA

Kaundinyapura (20°55′ N and 78°05′ E) in Chandur taluka of Amaraoti district lies on the western bank of the Wardha river. It is interesting to note that the place has retained its old name through ages along with Vidarbha. Six chronological periods of the site can be drawn on the basis of the layers and unearthed objects. The first phase reveals Megalithic culture, the second pre-Mauryan, and the third one the Mauryan (300–100 B.C.); the fourth covers the Sātavāhana period (150 B.C.–200 A.D.), the fifth shows the late Sātavāhana period (200–250 A.D.) and the sixth stretches throughout the Muslim period.[e] Bhim Tekdi, a large artificial hill (about 220 metres in length and 108 metres in breadth) was selected as the venue of the excavations (Kdn-1) under the auspices of the Education and Social Welfare Department, Government of Maharashtra.

Glass beads have been found in the III, i.e. Mauryan period (300–100 B.C.) and the glass objects are beads, ear-plugs and ornaments, etc.

Beads. Ten glass beads[f] have been unearthed—1 from period III, 7 from period IV and 2 from the unstratified layer. Beads (5 in number) recovered from the Sātavāhana stratum (IV, i.e. 150 B.C.–200 A.D.) are copper and cobalt coloured circular cylinder with lug and groove collars. Among the unstratified specimens, which are common to many Sātavāhana sites in the Deccan, are blue cylinder square beads with white oblique strips and beads inlaid with gold-foil. Besides, one annular of orange-coloured

[a] Lal, 13. [b] *IAR* (1963–64), 26. [c] *IAR* (1962–63), 12. [d] Dikshit (9), 46.
[e] Dikshit (7), 27. [f] Dikshit (7), 98–99.

devitrified glass was recovered from the Maurya level. This type of beads had wide distribution throughout India wherever copper ores are found. Another most interesting type is a stratified eye bead (about 1 cm in length and 1 cm in diameter) of blue glass, i.e. having blue eyes surrounded by white rings. This was recovered from trench C below the pebble foundation of a wall. Such stratified 'eye' beads are characteristic of the Maurya period and have been recovered largely from Taxila. This type seems to be of Mediterranean origin and was imported into the country. It appears to have been manufactured by the superimposition of different coloured glasses one over the other.

Glass bangles. Four bangle[a] pieces were associated with two layers—Muslim (in Trench B3) and Mauryan (Kdn-2). The first two (i.e. of Muslim layer) are stratified type of glass, triangular in section and have a dull opaque grey core within which is again overflowed opaque sulphur-coloured yellow glass. In one of these, at regular spaced intervals, a strip of bright red glass with small studs of milky white glass is affixed at the triangular apex. The second specimen (i.e. of Mauryan layer) represents a flattish strip of dull grey glass coated with a sap-green glass. It is overlaid with a prominent ridge of identical glass having a short red border at the apex, which in turn is set with small beads of white glass at short intervals. Another unstratified sample from the same trench comprises a small strip of yellow glass, rectangular in section, overlaid with a bright leafy-green glass.

Fragments of bangles recovered from the site Kdn-2 show some advance in the technique of glass fabrication. One of them is a mis-shaped wire of drawn glass, indicating the manufacture of glass at the site. It has a dull black surface with a dark patina on the exterior, resulting from the salts contained in the batch. Another one (a pentagonal cross-section with sharp edges) is a green glass considerably disintegrated, with pitted surface all over.

Besides these, four or five ear-plugs[b] of black, green, bluish green and vermilion opaque colour have been recovered from this site.

KAUSAMBI

The remains of ancient Kausambi can be traced in a mass of mounds on the left bank of the Yamuna about thirty-two miles south-west of the holy city of Prayaga (modern Allahabad). From 1937 to 1950 two excavations were carried out here under the guidance of the Archaeological Survey of India and the University of Allahabad respectively. The site has its three different phases: stratum I is associated with the painted grey ware period (first quarter of the first millennium B.C.); stratum II—representing the N.B.P. ware period (600–200 B.C.) and stratum III—revealing the occurrence of the post-N.B.P. ware (200 B.C.–325 A.D.).

Among the other objects, the excavation yielded sixty-three samples of glass bangles.[c] Glass seems to have been the most popular material. Their colours are blue, black, green, yellow, ash-green and polychrome. In certain specimens, mostly those in black, blue and green, a narrow stripe of a chain of bubble-like dots of white colour runs like a mid-rib around the outer surface. Blue bangles show the largest

[a] Dikshit (7), 124. [b] Dikshit (7), 127–28. [c] Sharma (GR), 93–94.

number of shades including sea-blue, light blue, violet-blue, sky-blue, etc The colour of green glass ranges in shade from light to dark.

Glass beads[a] found at the site are nearly five hundred and ten in number of which wire beads constitute nearly half the total; beads also occur in a fair quantity and moulded ones are comparatively few in number. Most of the beads are opaque and several have been crushed to powder due to corrosion. The glass is generally of a good quality; their colours are blue, blue-green, green, black, copper-red, and yellow and violet, which are extremely rare. The blue glass beads are occasionally found to contain a large number of impurities which float like red and purple mist in the glass, and without destroying some of them it is difficult to state whether they contain ferruginous matter. The colouring agent for most of the beads seems to be copper and its oxides, cobalt being used for few specimens. A typical orange-coloured glass on examination proved to be devitrified. The presence of a large number of unfinished and unbored specimens seems to suggest that beads were manufactured at the site. A few among them seem to be of foreign origin. These appear to have been prepared by a technique different from the other ones. The glass in the lower levels is generally of a better quality than in the upper strata where the evidence of mass production is clear from the number of the common types. The shapes of the beads are generally oblate, cornerless cube, bicone circular, cylinder tube, cylinder square, flat oval tablet, barrel circular, short bicone, etc., covering a period from *c.* 200 B.C. to 300 or 400 A.D.

These beads may be classified under the following heads according to their colours:

Blue glass beads. The colour of a large number of blue glass beads ranges in shade from a deep cobalt to a pale blue. These are prepared mostly by the cane process and are fire-polished. Their shapes are oblate, cornerless cube, bicone circular, cylinder tube, etc.

Blue glass with a layer in between. These deep cobalt-blue beads are inlaid with a white porcelain-like layer. An analysis of this white layer shows that the colour is due to tin-oxide. Quite a large number of such beads exist in surface collections and are preserved in different museums. They are of short square and cylinder shape and are attributed to the early centuries preceding the Christian era.

KESARIPALLI

From Kesaripalli,[b] in the Guntur district, a few glass beads are reported to have been found in association with Ikshvaku coins and rouletted ware.

KOPIA

Kopia,[c] situated in Uttar Pradesh about 31 miles from Basti, is said to have derived its name from ancient 'Anupia', a place where Gautama Buddha took shelter after his renunciation of the world. The mound of Kopia is a large and striking one, extending about a mile and rising about 40 ft from the surrounding fields or about 60 ft from the water level of the nearby Anoma river. Towards the east of the mound

[a] Sharma (GR), 114–19. [b] *IAR* (1961–62), 2. [c] Roy and Varshney, 366–68.

at a distance of approximately a furlong lies an extensive flat land, about 15 ft above the surrounding fields. This table-land has been reported by M. N. Nagar, Curator of the Provincial Museum at Lucknow, to be the site of an ancient glass factory. Innumerable glass beads and glass slag of various sizes and shapes and numerous lumps of melted glass in various stages and colours were scattered there. Among them is a big massive slag of glass about 120 lbs. in weight (18″ × 9″ × 12″ in size). The age of this glass factory, according to M. N. Nagar, is attributed to the 5th century B.C. because of the similarity of Kopia glass beads with those of the beads and other objects contained in a steatite casket near a village of Piprahwa Stupa in Bindpur estate in Basti district. The date of the casket is presumed to be about 5th century B.C. from an inscription on its level. Among the specimens mention may be made of a number of clay crucibles, which were possibly used for heating or melting glass. One such clay crucible was chemically analysed. Some of the glass specimens have been analysed by P. Roy, of the Central Glass and Ceramic Research Institute, Jadavpur, Calcutta. These specimens are: fine (perforated) beads of yellow, blue and black colour (diameter about 1.5 mm to about 3 mm), greenish blue, greyish blue, pale greenish yellow, coral red, opaque white and transparent. They have varied shapes like tabular elongated, lozenge, perforated, unperforated, spherical, barrel, round, triangular, square, hexagonal, flat, tapered longitudinal, etc. There is also a fragment of a bangle of black opaque glass—flat on the inside and semi-cylindrical on the outside. All these pieces are soda-lime glasses containing a high percentage of alumina. Among the findings the most striking specimens are the tiny glass beads perforated with extremely fine holes, which are very difficult to see with the naked eye. These are also brilliantly coloured and highly polished.

KUMRAHAR

Kumrahar is the well-known site of Mauryan pillared Hall at Pataliputra (Patna). This was excavated by D. B. Spooner in 1912–14. The occupation of the site is divided into six phases (on the basis of the type-finds) beginning from the 2nd century B.C. to the 18th century A.D. Of the diverse objects, glass beads[a] were recovered from phases III (100–300 A.D.) and IV (300 to 450 A.D.). The glass is either translucent or opaque and the range of colour is limited. Green and blue are the more common colours. The shapes of the beads varied, being hexagonal, spherical, cylindrical, elliptical, drum-shaped; some were prismatic square.

KURUKSHETRA

An excavation was carried out by Mr. Sahni in 1921–22 on the site of Kurukshetra, the scene of the great war fought between the Kauravas and the Pandavas. The earliest references to this holy land are to be found in the *Śatapatha Brāhmaṇa* and *Aitereya Brāhmaṇa* which go back to the period much earlier than the composition of the *Mahābhārata*. The mound that was selected by Sahni for tentative exploration is known as Raja Karna Ka Kila and is situated upwards of a mile to the south-west of the holy tank of Thaneswar. Several minor antiquities were picked up on the

[a] Altekar and Misra, 132.

surface. They consist of ancient pottery, copper coins, terracotta figurines, pieces of glass and glazed pottery of the Mughal period.[a] A chemical analysis of the bluish green bangle, porous and partly decomposed, has been made by Sana Ullah.

MAHESWAR AND NAVDATOLI

Maheswar lies on the northern bank of the Narmada, about 50 miles south of Indore, while almost exactly opposite on the southern bank is situated the hamlet of Navdatoli (or Nauratori), i.e. boatman's village. Maheswar received its historical importance as a taluk town in the Nimad (Nimar) district under the Holkars of Indore. The sequence of site of the excavation can be divided into seven phases[b] beginning from the early stone age to about the Muslim–Maratha periods. The dating of these layers was determined by C-14 test. According to the report, the date of the top layers of the chalcolithic habitation has been assessed as *c.* 1000 B.C. (3294 ± 125) and of the earliest layer as 1500 B.C. (3503 ± 128). Twenty samples of the excavation were sent to the Physics Department of the University of Pennsylvania for C-14 dating. From the result of the examination of four samples the Department has come to the conclusion that there were four phases of the chalcolithic habitations of the site.

Among the other objects, glass, though known in phase III (3rd century B.C.), was mostly in use in the later periods. The specimens are glass beads, bangles (both polychrome and monochrome), discs, seals, pieces and slags etc.

Beads. Several fragmentary and eleven intact specimens of glass beads[c] were recovered from Maheswar. Of the intact ones, eight came from layers of phase VI (100–500 A.D.), two from phase V (100 B.C.–100 A.D.) and one from phase VII (Muslim–Maratha period). They show a wide range of shapes such as spherical, truncated barrel, globular, hexagonal, cylindrical and irregularly circular. Their colours are deep blue, deep green, yellow, sea-green and soiled white.

Among the four glass beads from Navdatoli,[d] one came from surface collection and three came from stratified layers of phase III and phase VII. They are of flat, circular, conical and globular shapes and of green, ash-white and dark blue colours.

Bangles. The bangles are both monochrome and polychrome, the former being more abundant than the latter. Of the monochrome type six hundred and seventy-three pieces were recovered, of which fifty-three came from Navdatoli trenches. Of the bangles unearthed from Maheswar, 95 per cent came from the layer of phase VI. The use of glass was known to its people from early historic times.[e] Of the polychrome bangles only thirty-four pieces were recovered from Maheswar and two from Navdatoli.

The varieties of shapes of the monochrome types of bangles from Navdatoli are plano-convex, triangular, round, oval triangular with rounded apex, triangular with ridged apex, with straight sides, rounded edges, etc. Their colours are green, yellow, red, purple and black. Besides, these bangles show various combinations of shades like turquoise green, sap green, hooker's green, dark purple, honey-coloured, Indian-

[a] *ASI/AR* (1921–22), 46–48. [b] Sankalia, Subba Rao and Deo, 191.
[c] Sankalia, Subba Rao and Deo, 186. [d] Sankalia, Subba Rao and Deo, 180.
[e] Sankalia, Subba Rao and Deo, 215–16, 220, 57–58.

red, cobalt blue, ultramarine blue, turquoise blue, deep chocolate, cream and lemon yellow. The bangles of the polychrome type show colours like Indian-red, jet black, lemon yellow, chrome orange, light yellow, dark olive green, light cream, sap green, turquoise blue and chocolate, etc.

Besides bangles, other objects of glass were not many. The most important of these, recovered from phase IV (*c.* 400 B.C.) of Maheswar, is a seal with an elephant impression on it. It is a squarish piece of black glass, characterized by punch-marked coins.[a] It has been analysed[a] by Dr. B. B. Lal, Archaeological Chemist, Govt. of India. The tablet (*c.* 300 B.C.) is composed of dark, amber-coloured soda glass. The glass is translucent to opaque. The tablet is slightly weathered and shows a network of cracks on the surface. A whitish deposit of silica is noticeable inside the cracks. The fracture is conchoidal, characteristic of glass. Chemical analysis shows that the colour of the tablet is due to iron compounds. Its hardness lies between 5 and 6 and it has a specific gravity of 2.41. The tablet shows that it had been moulded with meticulous care and is remarkably free from devitrification. The other two fragmentary and two complete pieces of glass discs, found in these sites, are perhaps of the same period. Three more slag pieces, an unperforated cylindrical rod and a specimen of devitrified glass were also found from layers V and VI.

MASKI

Maski (15°57′30″ N. Lat. and 76°39′15″ E. Long.) lies in Lingusugur Taluk of Raichur district, formerly in Hyderabad state and now included in Karnataka. To the north of the village flows the Maski nullah, a tributary of the Tungabhadra. The four stratigraphical phases of the site cover a period extending from chalcolithic or early Bronze Age to the Muslim period, and the chronology of the strata and structures may be determined by the evidence of microlithic and megalithic culture, coins and inscriptions. Phase I covers the period of the first millennium (chalcolithic) to the fourth century B.C.; phase II extends over a period from the 2nd century B.C. to 1st century A.D.; phase III relates to the period covering 1st to 3rd century A.D. The medieval period extends from 1000 to 1600 A.D.[b] Glass objects excavated from Maski are beads and bangles.

The range of colour of the beads is very limited. Shades of blue and green are the most common colours throughout the whole occupation including the medieval period. Other colours represented are black, yellow, white, amber and shellac red. The material is either translucent or opaque. The commonest shapes are the standard cylinder (or sometimes barrel) and circular; other forms comprise bicone truncated circular, spherical, long cylinder, grooved circular, long convex square and long cylinder circular.[c]

Most of the specimens of glass bangles are incomplete. Their colours are sea-green, turquoise green, amber, red, blue and yellow. Most of the bangles are opaque. Instances of stratified glass also occur. In some cases a strip of opaque yellow is seen on translucent amber, relieved on the top with small brownish dots, while in others yellow wire-like strips form the binding edges for a channelled surface of sea-green.[d]

[a] Sankalia, Subba Rao and Deo, 215–16, 220, 57–58.
[b] Thapar (1), 10–16. [c] Thapar, 107. [d] Thapar, 111–12.

The fragmentary polychrome glass bangles with variegated designs from Maski, ascribable to 14th to 15th century A.D., have been studied by Dr. B. B. Lal.[a]

The fragment of a bangle on the right clearly shows four colours. The rim is green in colour. The adjoining band is a combination of pale-yellow and reddish glass arranged as a twisted pattern. The third band is liver-red and the innermost band, which is broadest, is composed of pale yellow glass covered with a thick lemon-yellow glaze. The sample shows a remarkable workmanship in the execution of designs. The glass used in the preparation of this polychrome bangle is opaque to translucent and the colours of the various bands have been found to be due to presence of copper and iron. The colour of the green glass has been produced by the combined effect of oxides of iron and copper. The yellowish colour is attributable to iron oxide. The liver-red colour has been found to be due to oxide of copper. The lemon-yellow colour has been produced by the oxide of iron. A cross-section of the bangle showing the variously coloured glass bands in juxtaposition was examined under the microscope in reflected light. This photomicro shows four distinct parts representing the four bands. The part at the left end of the photomicro is green glass of the rim, and the part at the right end is pale yellow glass having a layer of lemon-yellow glaze. The lemon-yellow glaze stands out as a distinct layer on the three edges of the band.

The other specimen examined is composed of pale yellow opaque glass covered with a thin layer of lemon-yellow glaze. The yellow colour is due to the presence of oxide of iron. The cross-section of the specimen is also shown in reflected light. The lemon-yellow glaze is seen lighter in shade as a layer round the edge of the specimen. The glazed surface of the specimen was further examined by the ultropak for the study of the surface features of the glaze. The spherulitics of the surface caused by incipient fusion of the glaze are also shown. The characteristic crackle or crazing which is a feature of most glazed surfaces is also visible in the lower part (light) of the photomicro.

The central specimen shows two colours, bottle-green and yellow. The bottle-green colour is due to the combined effect of iron and copper, the yellow colour is attributable to the oxide of iron. The body of the bangle is made of bottle-green opaque glass and the designs have been produced by fusing to this body plain strips of yellow glass as well as strips showing twisted patterns in yellow and green glass. A polished cross-section of this piece was examined under reflected light. In this photomicro, the white circular parts to the left and the upper part of the central portion of green glass of the body represent yellow glass. The dark part seen in the centre of the latter represents green glass which has been twisted with the yellow glass to produce the design seen very clearly in the central specimen. The glass used is opaque. The designs have obviously been executed by stitching to the body of the bangle carefully prepared bands of glass of different colours.

MASON

The excavation at Mason in the district Ghazipur was carried out by Sri R. B.

[a] Lal (1), 51–52.

Narain of the Sanskrit University, Varanasi. Among the finds a circular glass object[a] was recovered from this site.

NAGAR

A small scale excavation was conducted at Nagar in the district Kaira, in the Taluk Cambay by Maharaja Sayajirao University of Baroda. Layer III of this excavation covering a period of first to ninth century A.D. yielded red polished ware, Roman amphorae, burnished black ware, glass beads,[b] etc.

NALANDA

Nalanda (in Patna district) is another prominent site of archaeological importance. Its area extends over some 16,000 feet N-S by 800 feet E-W and contains the remains of numerous bricks, stupas and vihāras beneath its many debris-strewn mounds. It was famous for the Buddhist University and was the most important centre of medieval Mahāyana Buddhism. The excavation of the site reveals in all nine successive levels representing a sequence of monasteries which range in date from approximately the 6th to the 12th century A.D.[c] The important antiquities excavated during 1920 to 1921 are pieces of coloured glass, crystal beads, metal objects and plates and a seal resembling the type of Maukhari seal (6th or 7th century A.D.).[d] A number of glass objects of various colours, light blue, sky-blue, green, opaque beads of red glass, decayed glass have been analysed by Sana Ullah, the Archaeological Chemist.

NASIK AND JORWE

Nasik[e] (N. Lat. 20°, E. Long. 73°51′), an ancient town, lies on both banks of the Godavari. It is the headquarters of the district of the same name, and forms a part of the state of Maharashtra. The four stratigraphical phases of the site cover a period extending from chalcolithic or early Bronze Age (i.e. 1500 B.C.) to Mughal–Maratha periods (1700 A.D.) and the chronology of the strata and structures may be determined by coins, inscriptions on potsherd and other objects.[e] The glass specimens were recovered from phases II (300 A.D., or 200–400 B.C.), III (200 B.C.–50 A.D.), and IV (1400–1700 A.D.). The varieties of glass materials are beads, bangles, rings, and other miscellaneous objects.

Beads. Out of seven glass beads,[e] six belong to phase III and phase IV and one comes from the layers of phase II (200–300 B.C.). The most interesting among these is a bead of composite glass which is technically called *blotched*. It is of yellow matrix covered over by green glass. Besides the blotched bead, there was another type known as gold-foil bead. Shapes of a few varieties are noticeable, such as low truncated, barrel and globular. The two most common colours are green and blue.

Bangles. Both monochrome and polychrome glass bangles[e] were recovered almost in the same quantity from all the above-named layers. Of the nineteen fragmentary glass bangles, sixteen came from stratified layers.

[a] *IAR* (1967–68), 47. [b] *IAR* (1963–64), 10. [c] *ASI/AR* (1921–22), 46–48.
[d] *ASI/AR* (1920–21), 33–53. [e] Sankalia and Deo, 1, 27–29, 96–97.

Nine monochrome pieces, both decorated and plain, were recovered from this site. They show a triangular section and are also plano-convex and more or less square in shape. Their range of colours includes chocolate, blue, green, black and purple. The polychrome type shows a limited range of colours with yellow and its shades as the principal one. But green and white appear to have been the most popular colours.

Thirty-three other objects of glass[a] consisting of discs and pieces of highly disintegrated glass were also found.

Of the seven glass discs, five finished specimens of similar shape with a groove at the surface of the circumference have been unearthed. They are of light blue, white, vermilion colour.

A single fragment of a black glass ring (breadth 11 mm) and six fragments of weathered glass were recovered.

A number of glass and glass-like objects have been analysed by Dr. B. B. Lal.

NEVASA

Nevasa[b] (19°34′ N. Latitude and 75° E. Longitude) is situated on the Pravara, a major tributary of the Godavari. The town of Nevasa is located on both banks of the river—the northern bank is called 'Nevasa budruk' (large), and the southern 'Nevasa khurd'. The materials found on excavation have been grouped into six phases extending from the early palaeolithic (150000 B.C.) to Muslim–Maratha period (1700 A.D.). Phase IV (Early Historic)[c] has been dated by Sir Mortimer Wheeler to be the 1st century B.C. It yielded the Northern Black Polished ware sherds, black-and-red wares, Margon wares, and specimens of glass beads. A large number of glass beads and bangles have also been recovered from phase V with the help of C-14 dating. The C-14 date for charred grains from the soak-pit is 1846 $\pm$ 106, which is in full agreement with the unearthed coins of the Roman Emperor Augustus. These are again associated with the late Sātavāhana coins of Gautamiputra Śatakarṇī and Yajñaśrī Śatakarṇī. On the basis of these evidences it may be assumed that the date of phase V is *c.* 1st century B.C. to 2nd–3rd century A.D.[c] Specimens of the best variety of glass come from the levels of phase V, as evidenced by an exquisite bubbleless blue glass and fragments of very thin glass bangles of the same colour. Various other antiquities indicative of Indo-Roman contacts are also characteristic of this period at Nevasa. Real indigenous workmanship, however, is seen at its best in the glass materials of phase VI from where a large number of glass beads and bangles were unearthed. This period may be dated to about the 14th to 18th century A.D. (Muslim–Maratha period) on the basis of the evidence of Tughlaq and Bahmani coins. It is interesting to note that though glass was known during the period of phase IV, it developed as a cottage industry only during the period of phase VI. This is, according to some scholars, due to the cultural contact with the Iranian Muslims of the Bahmani dynasty in the 14th and 15th centuries.[c] The art of polychrome glass bangles, according to Sankalia, was

[a] Sankalia and Deo, 99–100. [b] Sankalia *et al.*, 1.
[c] Sankalia *et al.*, 64–65, 69–70, 441, 354.

introduced by Iranian Muslims in the 14th and the 15th century A.D.[a]

The glass specimens are beads, bangles, rings, vessels and slags.

Glass beads numbered about three hundred and forty-eight and constituted nearly one-fifth of the aggregate materials. Next to steatite they represent the second largest group of beads. Besides the colouring of glass, these beads reveal various techniques of glass and bead manufacture. Glass beads are restricted mostly to phase V (50 B.C.–200 A.D.) which represents the most flourishing period in the history of Nevasa.

The glass beads also reveal a variety of shapes—collared, short barrel, short truncated barrel, short cylinders, tabular, tablet-barrel, short truncated bicone, collared flat, square cylinder with concave ends, segmented, segmented gadrooned, square truncated barrel, hexagonal biconal, annular, onion shaped, collared cylinder, gadrooned globular, gadrooned short cylinder, gadrooned short barrel, lug collared, cylinder disc, irregularly circular, etc.

Colour. Beads are mostly green, blue and yellow in colour. The green-coloured beads reveal different shades of green: persian green, turquoise green, royal green, light hooker's green, sap green, emerald green. Also available are beads of various shades of blue, such as ultramarine blue, turquoise blue, cobalt blue, persian blue, etc. Yellow beads also show different shades such as lemon yellow, yellowish green, yellow ochre, buff lemon, raw sienna, chrome yellow, gamboge yellow, etc. Besides these, there are beads of other colours: red, Indian-red, copper-red, brilliant red, red chocolate, pomegranate coloured, snuffy brown coloured, grey, white, purple, black beads, etc. Beads with gold-foil and with lemon yellow matrix were also recovered.

Bangles. Glass bangles are of two categories: monochrome and polychrome. The first type is more than six times the number of the second, being 504 and 81 respectively.

The colours employed in the case of monochrome bangles show a limited range, such as black, yellow, green, blue and red. Black, however, seems to have been a favourite colour, representing more than half of the entire quantity of monochrome bangles. Their sections vary, being plano-convex, triangular, square, rectangular with convex ends, triangular with rounded apex. From the distribution it is clear that black glass bangles with plano-convex triangular section were most abundant in the late phase of period V (50 B.C.–200 A.D.) and in layers of period VI (1400–1700 A.D.).

Green bangles. Fifty fragmentary green glass bangles show a variety of shades in basic green, such as sap green, hooker's green, emerald green, permanent and turquoise green. The categories of the sections of the green glass bangles include two varieties in addition to those of the black glass bangles, i.e. circular and channel.

Yellow bangles. Three pieces of yellow glass bangles, devitrified and plano-convex in section, have been recovered. Their shades are gamboge yellow, lemon yellow, yellow ochre and chrome orange.

In the red coloured bangles, a singular specimen of a combination of burnt sienna chrome orange shades was recovered.

Of the forty pieces of bangles unearthed, two shades of blue glass with ultra-

[a] Sankalia (I), 354–360.

marine and persian blue were recovered. Their sections are plano-convex, triangular, rectangular, circular, three arched, etc.

The polychrome glass bangles may be divided into the following categories on the basis of the colour of the main basal band of glass: yellow, red, black, green and blue.

Glass rings. Of the twenty-six specimens of rings, all except three are monochrome. They are grouped basically in four colours, namely black, green, red and blue, and are mostly opaque with a variety of shades.

Green rings with shades of emerald green, sap green and persian green are ten in number, with plano-convex, circular and triangular sections. Five red glass rings in shades of bright vermilion and Indian red are rectangular and plano-convex in section. The shades of blue glass rings are ultramarine, royal and turquoise.

Polychrome glass rings may also be sub-divided into a variety of sections such as plano-convex, triangular and round, with different shades of colours like persian green, burnt sienna, sap green, light grey and ultramarine blue.

Rim fragments of twelve opaque glass vessels have been recovered from the levels of period V, i.e. during the time of Indo-Roman contact (50 B.C.–200 A.D.). They are of light emerald green, persian green and blue in colour. A fragmentary piece of rod of Kohl stick was also recovered.

Out of the fourteen pieces of glass slags, eight came from the topmost layer indicating that there was a glass-making industry. Varieties of different coloured slag specimens suggest that the glass-makers were quite skilful and careful workers.

PAIYAMPALLI

The excavation at Paiyampalli[a] in the district of North Arcot was carried out under the guidance of S. R. Rao in 1964. The work has brought to light the products of two cultural periods, namely the neolithic (period I) and megalithic (period II). According to C-14 determinations of the charcoal samples, these have been dated as 1390 ± 200 B.C. (period I) and 315 ± 100 B.C. (period II) respectively. From the picture of the site it is clear that glass bangles and beads along with other objects were used as personal ornaments by the people of period II.

PATNA

Among the other findings of the excavation at Kumrahar and its surrounding region in Patna[b] by Dr. Spooner, five glass seals deserve mention here. The positive sealings on the specimens, excavated between 1914 and 1926, are attributed to 300 to 200 B.C. They are Brāhmī in character and are now deposited at the Patna Museum. These specimens are described according to their colour, size and datings as follows.

(1) A sealing of crude blue glass, belonging to pre-Mauryan period with a diameter of nearly ⅞", thickness ⅛" and sp. gr. 1.71. The specimen was found by Manoranjan Ghosh.

(2) A sealing of greenish glass (*c.* 250 B.C.), circular in shape, with a diameter of about ½", also discovered by Manoranjan Ghosh, at Bulandibagh.

(3) An oval shaped greenish transparent glass disc (*c.* 200 B.C.) with a diameter

[a] *IAR* (1964–67), 22; (1967–68), 26–30. [b] Jayaswal (1), 190–93; 200–201; (2), 1–6.

of $\frac{5}{8}''$, thickness $\frac{1}{2}''$ and sp. gr. 1.71. It was found by Spooner at Kumrahar in 1914–15.

(4) A clear transparent rectangular glass disc with a greenish tinge and having slightly bulging sides (*c.* 200 B.C.). Its dimensions are $\frac{5}{8}'' \times \frac{5}{8}'' \times \frac{1}{8}''$, with sp. gr. 1.71. It was found by Spooner in 1916 at Kumrahar.

(5) A blue or transparent glass disc (*c.* 200 B.C.) with a diameter of $\frac{9}{16}''$, thickness $\frac{1}{8}''$ and sp. gr. 1.78. It was discovered by Spooner in 1916 at Bulandibagh.

Besides the discovery made by Dr. D. B. Spooner at Kumrahar and its surrounding region, excavation was also undertaken in four isolated areas in Patna city, viz. Gulzarbagh Government Press Playground, Mahabirghat, Begam Haveli and Shah Kamal Road[a] by the K. P. Jayaswal Research Institute, Patna, under Sri Vijayakanta Mishra. Five periods of occupation ranging in point of time from *c.* 6th century B.C. to the seventh century A.D., followed by a gap of nearly one thousand years between 600 and 1600 A.D., were revealed. Of these, period V (1600 A.D. and later) yielded glass beads along with terracotta figurines with typical Muslim and Maratha head-dress, silver coins of Shah 'Alam, etc.

PRAKASH

Prakash is one of the chalcolithic sites in the Tapti valley. It reveals four cultural periods[b] extending from the 17th century B.C. to 11th century A.D. The specimens recovered from the site include beads, bangles, rings, etc. The presence of a few unfinished specimens at various stages, however, indicates that beads were perhaps manufactured locally. The materials used for the manufacture of these beads are semi-precious stones like quartz, rock-crystal, carnelian, agate, jasper, shell and glass. The glass beads[c] are nineteen in number and have been unearthed from phases III (middle of 2nd century B.C. to end of 6th century A.D.) and IV (end of 6th century to 11th century A.D.). The shapes of the beads are gadrooned, club-like, pendant barrel-like, spherical, cylindrical and square. Their colours are yellow, shades of green, blue and black, the composite ones with a yellow matrix and green coating. The beads were made either by spirally winding or by drawing canes or by the simple drawing of the viscous matter on the tip of an instrument. Besides, the distinctive technique of perforating these by a poker, which produces a burred edge on one side, is also evident on some beads.

Glass bangles forty-five in number have been recovered from three phases, i.e. from II (6th–1st century B.C.), III (2nd century B.C.–6th century A.D.), IV (6th to 11th century A.D.) and also from an unstratified deposit. The occurrence of monochrome glass bangles during the pre-Christian era is noteworthy in this connection. Excavations at Nagda and Ujjain have also indicated the use of monochrome glass bangles in 6th–5th century B.C. Similar evidence is also available at Sravasti, where translucent sea-blue and light green monochrome glass bangles have been found in association with the Northern Black Polished ware.

Both monochrome and polychrome types were found. The monochrome ones are of two varieties—translucent and opaque. The translucent type with light green and blue colours and with pentagonal and circular sections is stratigraphically earlier

[a] *IAR* (1967–68). [b] Thapar (2), 24. [c] Thapar (2), 109.

than the opaque one. The latter shows black, green and lapis lazuli (blue) colours and has circular, rectangular and plano-convex sections. Black coloured bangles are more abundant in phase IV (6th to 11th century A.D.). The occurrence of a good number of non-circular deformed specimens of glass bangles seems clearly to suggest that there was in all probability a local industry and the majority of the opaque bangles were apparently made by the pulling out of the plastic glass to the required shape. The translucent type with a pentagonal section appears to have been prepared by the use of a mould.

Polychrome and bichrome types of glass bangles were found in phases II and IV (i.e. 2nd century B.C. to 11th century A.D.). The bichrome ones show a basal black colour or a tan band over which either a plain thin strip or a design in yellow dots is applied and fused with the body. The combinations of yellow and green over basal black is much in evidence in the polychrome type. That the polychrome glass bangles were available from the levels corresponding to the close of the first millennium A.D. is further supported by the findings from Ujjain and Yeleswaram.

RAIRH

The excavation at Rairh,[a] 32 miles south-west of Rangmahal (Bikaner, Rajputana), was carried out by the Archaeological Department of the former Jaipur state in 1938–40. The site corresponds to the period extending from *c.* 3rd century B.C. to 2nd century A.D. and is said to have revealed glass beads of very good quality.

RAJGIR

Rajgir,[b] in the district of Patna, is situated outside the hill-girt valley and is supposed to have been founded by King Ajatasatru, the Magadhan contemporary of Buddha. The excavation at the New Fort at Rajgir was undertaken by the Mid-Eastern Circle of the Survey. Some glass beads in association with iron objects were recovered from its deposit.

RAJGHAT

The excavation at Rajghat,[c] in the district of Varanasi, brought to light six periods of human occupation, ranging from *c.* 6th–5th century B.C. to 17th century A.D.

In association with other objects, namely beads of terracotta, copper, and a few terracotta human and animal figurines, glass objects were recovered successively from the three layers corresponding to the period 6th century B.C. to 4th century A.D. Polychrome type of glass bangles were recovered from phase VI (14th–17th century A.D.).

During 1960–61 three trenches were dug on the northern, eastern and southern (Ganga) sides. It is assumed that the earliest occupation of the site went back to the first quarter of the first millennium B.C., while the uppermost levels could be dated to 17th century A.D. Glass pendants and bangles were recovered from the 3rd (from the beginning of the Christian era to 300 A.D.) and 4th (300–700 A.D.) layers.

[a] Puri, 41. [b] *IAR* (1961–62), 7. [c] *IAR* (1957–58), 50; (1960–61) 35; (1963–64), 58–59.

RANGMAHAL

The excavation at Rangmahal[a] (Bikaner, Rajputana) reveals a period approximately contemporaneous with the Kushana and Gupta eras. In 1952–54 some Swiss archaeologists made an excavation which throws considerable light on the nature of the glass specimens recovered there. Varieties of glass beads of different shapes such as oblate, long tube, with bluish green, blue and white colours were recovered. Besides, fragments of bangles of blue glass with diamond-shaped facets and of black glass twisted into spirals, were found here, which are said to have belonged to the Kushana period.

RATNAGIRI

Hundreds of small sealings of fragile unbaked clay of diverse shapes, sizes and legends, a large number of bronze and a few porcelain and glass pieces belonging to the 8th century A.D. were recovered from the floor of the western cell of the monastery at Ratnagiri[b] in the district of Cuttack.

RUPAR

The excavation at Rupar,[c] a well-known site in the Simla hills near Ambala, has yielded a few glass bangles in association with the painted grey ware (1100–400 B.C.).

SAMBHAR

Sambhar,[d] an ancient site near the salt lake, was explored by Rai Bahadur Daya Ram Sahni in the years 1936–38. The site has its occupation extending from about the 3rd century B.C. to the Gupta period and a little later. Its Kushana levels have yielded frog-shaped amulets of white iridescent glass.

SATARA

A large number of antiquities comprising early stone age tools, microliths, terracotta figurines, shell and glass bangles and broken stone images have been collected from the explorations in and around Aundh in the district of Satara[e] in Bihar.

SIRPUR

Sirpur,[f] in the Chattisgarh Division of Madhya Pradesh, enhanced its glory for the discovery of a glass industry flourishing there at the end of the ancient period and the beginning of the Muslim rule. The excavation in the township area near the cluster of monastic buildings revealed a large number of thick potsherds of storage jars (*rañjans*) in which glass was melted or annealed in ancient times. Besides, the existence of a large quantity of glass slag and drawn wires suggests that glass was in all probability actually made and worked there. Varieties of bangles seem to have been mainly manufactured there. For example, extraordinary thick rods, nearly 2–3 cm in thickness, of amber and brandy coloured glass were used for bracelets; another variety, thinner in size, was used as a baseplate, over which was stuck a rod of dull

[a] Ghosh (A) (2), 168–69. [b] *IAR* (1958–59), 42. [c] Sharma (YD) (1), 121–28.
[d] Hendley, 29 ff; Sahni, 41, 54. [e] *IAR* (1961–62), 34. [f] *IAR* (1954–55), 22–26.

opaque green-blue glass with various designs. Others, found in large numbers, are both flattish and triangular in section. Besides these, monochrome bangles of a very simple technique were also available. Dark leafy green, amber, purple and translucent green were the chief shades of colour employed for the preparation of these bangles and bracelets.

SONPUR

The excavation at Sonpur[a] in Gaya district reveals three periods of continuous occupation, which began in the first quarter of the first millennium B.C. and ended in the early centuries of the Christian era. Period II exhibits specimens of beads of terracotta, stone and glass, weights of steatite, etc. in association with Northern Black Polished wares. During the years of excavation in 1960–61 and 1961–62 glass specimens have also been recovered from period II of the same site.

SOPARA

The excavations of the stupa at Sopara,[b] which exhibited good evidence of glass specimens, were carried out by Pandit Bhagwanlal Indraji in 1886. The date of the stupa may be assumed to be 188–190 A.D. on account of the finding of a silver coin of Yajñaśrī Śatakarṇī there. In the year 1941 a resumed excavation yielded a small bottle of translucent blue glass about 2 inches in height, having an ovoid body and a tall cylindrical neck.

SRAVASTI

At Sravasti[c] in Uttar Pradesh, beads of green glass are reported from a late phase of Painted Grey Ware Culture (i.e. *c.* 1100–4th century B.C.). Besides, there are a few beads of stratified glass corresponding to mid-third century B.C. to the middle of 1st century B.C.

SULUR

A large number of glass beads belonging to about 3rd century B.C. to 1st and 2nd century A.D. have been found both in the megalithic tombs and in the middens around them at Sulur, in Coimbatore district. The following three varieties of beads have been recovered from the megalithic tomb at Sulur: (1) whitish glass with a specific gravity of about 3.43; (2) barrel circular bead of blue glass with white oblique strokes in the middle; (3) a cuprous oxide bead (turned into pale brown colour) with large air bubbles and a corroded surface.

Besides, beads numbering about 148 have been found in the middens near the megalithic tombs at Sulur. They are of green (72), red (29), black (11), blue (24), blue zon (1), yellow (3), opaque orange (1), imitation garnet (2), pale brown (1), white (1), clear (2) and corroded (1) glass. It should be mentioned here that glass in the megalithic tombs was first noticed by Col. Tucker, but he did not publish any detailed account of his excavations at Sulur; the results were communicated by Beck.[d]

[a] *IAR* (1956–57), 19; (1959–60), 14; (1960–61), 4; (1961–62), 4–5. [b] Dikshit (9), 47.
[c] *IAR* (1958–59), 47–50. [d] Beck (2), 171–74.

TAXILA

The city of Takshasila or Taxila was situated at the head of the Sind Sagar Doab between the Indus and the Jhelum rivers and in the shadow of the Muree hills, where the rivers die down into the western plain.[a] The excavations at Taxila were carried out under the orders of the Government of India between the years 1913 to 1934 and were conducted by Sir John Marshall, Director-General of Archaeology in India. The excavated areas where the glass specimens were available are: (1) Bhir Mound, (2) Sirkap, (3) Sirsukh and (4) Dharmarajika stupa, the most conspicuous of Buddhist stupas. According to local tradition, the Bhir Mound was the most ancient of all the sites at Taxila. It is situated on a small plateau between the railway junction and the Tamranala. Of its four successive settlements, the uppermost dates from the break up of the Maurya empire to the coming of the Bactrian Greeks, the second from the Maurya period, the third from the 4th century B.C. and the fourth from the 5th to 6th century or earlier.[a]

According to Beck, there is no evidence of any glass at Taxila before the 7th and 6th century B.C.[b] The glass objects that have been recovered from Taxila comprise beads, bangles, small vessels, tiles and some miscellaneous articles. The glass beads from the fourth stratum of the Bhir Mound (*c.* 5th century B.C.) are twenty-five in number. Most of the beads are colourless and iridescent. Those that are coloured are blue, black, green, very dark green, grey, opal white, amber, etc. Two more glass objects, other than beads, which came from the same stratum are an ear-reel decorated with a rosette on one side and a part of a miniature casket. Both were made a fine variety of black or very dark green glass which has the appearance of obsidian and is free from quartz grain or other impurities.[c] The glass beads found in stratum III (*c.* 4th century B.C.) are 217 in number. The commonest colours are blue (135 specimens) and green (13 specimens). Rare colours are yellow, red and turquoise.[c]

In the stratum II (i.e. 3rd century B.C. to the overthrow of Maurya rule) glass appears to have been used for the manufacture of bangles, beads and seals. The shape of the bangles is generally plano-convex or plano-conical in section, but narrower in proportion to their thickness than the later specimens from Sirkap. The colours are blue, green and black.[d] Like the previous stratum, the commonest colours of the beads of this period are blue and green. Amber, yellow, orange, opaline and turquoise are represented by one or two specimens only. Black and red come a long way behind. In addition to some popular shapes like the scaraboid, faceted tabular, collared leech, triangular, hexagonal, barred, bud pyramidal pendant, etc., other shapes are much the same as in the previous period.[e]

The scaraboid is a characteristic Persian shape. The excessive use of the drill, observable in some of the seals, points in the same direction; in other seals Greek workmanship is noted. The pyramidal seals No. 5 and 6 are differentiated from the scaraboid seals not only in shape but also in their technique of engraving, which is done in the crudest fashion and without the help of the drill. It is probable that they were made at Taxila itself; in any case they were Indian.

[a] Marshall (3), I, 1, 2–8. [b] Beck (4), 2–8. [c] Marshall (3), I, 102, 105.
[d] Marshall (3), II, 684. [e] Marshall (3), I, 109–10.

The only glass object recovered from the stratum I (from the break up of the Maurya empire to the coming of the Bactrian Greeks) of the Bhir Mound is a spear-shaped pendant of green glass about 7″ long.[a]

The most interesting beads from the Bhir Mound are the series of "eye-beads".[b] The beads are virtually identical with the beads found around the Mediterranean and are dated 9th to 3rd century B.C. The date of exactly similar beads is given in connection with various other specimens. The resemblance is so close that these beads were either actually made in the Mediterranean area or at least by men who came from that area, or who had learnt how to make them from workmen who came from the Mediterranean country. Besides eye-beads, others are inverted flower pendant, plano-conical, scaraboid spacer, plano-convex circular, pear-shaped multi-spiral, hexagonal, barrel, tabular hexagonal bicone, square barrel, cornerless cube, etc.

The city Sirkap,[c] on the east side of Tamranala, was built by the Bactrian Greeks in the second century B.C. The principal area excavated in Sirkap is the lower city, north of the Hathial Spur. In this area seven successive strata of remains are distinguishable, extending from the surface to a depth of 18 to 23 ft and representing, from first to last, three to four centuries of occupation. Of these settlements the earliest (seventh) dates from pre-Greek times. The sixth and fifth belong to the Greek rule (*c.* 190–90 B.C.). The fourth, third and second date from Śaka times (*c.* 90 B.C.–25 A.D.). The top yielded a few fragmentary remains, which are referable to the period following the Kushana period (*c.* A.D. 60).

The glass beads from the sixth and fifth (*c.* 190–90 B.C.) strata[d] are twenty-five in number. Their shapes are spherical, gadrooned, followed by disk, oblate, barrel cylinder, hexagonal, collared, granulated, etc.; and colours are blue, yellow, blue with yellow waving, black, and red. In the fourth stratum (i.e. early Śaka period) both bangles and bead have been recovered.[d] The bangles are usually of a plano-convex or twisted cable pattern. The plano-convex pattern is sometimes varied by a midrib running down the outer side. They are fashioned chiefly out of pale and dark blue glass; a few specimens of black glass were also noticeable. Coloured glass was also used for the bezel. A fragment of a beautiful bowl of 'lace' glass (*vitro di trina*) was found in the second stratum (1st century B.C.).

The glass beads recovered are two hundred and fifty-five in number and are of opaque yellow, blue, green, amber, pale blue, blotched, and also of multi-coloured and colourless glass; opaque yellow seems to be the most favourite colour of the beads. Two of the glass rings[e] of the 1st century A.D. are furnished with bezels.

Besides, a piece of blue and white cameo-cut glass bowl has also been recovered, the technique of whose making seems to be the same as that of the well-known portland vase in the British Museum.[e] Other specimens are three complete conical-shaped flasks[f] of sea-green or jade-green colour. These, probably the largest specimens of intact ancient glass objects so far found in India, were formed by means of blowing. It has been concluded by some scholars that the Taxila craftsmen were acquainted with the art of glass-making and glass-blowing as well as with the more advanced art

[a] *ASI/AR* (1912–13), 41. [b] Beck (4), 20. [c] Marshall (3), I, 118.
[d] Marshall (3), I, 130, 135. [e] Marshall (3), II, 640–41. [f] Marshall (3), I, 194, 195.

of decolorising glass by means of manganese and colouring it with various metallic oxides.[a] According to Marshall, all the glass vessels or fragments of vessels, found at Taxila, are without doubt of foreign origin and nearly all are dated from 1st century A.D.

The number of ornamental glass beads[b] in Sirkap of the Śaka-Parthian strata (1st century A.D.) is about 2769. Only a very few glass vessels[b] were found and all of them seem to have been imported from the West as there is no evidence of the manufacture of glass objects at Taxila other than beads and tiles. At the extreme western end of the Hathial spur in Sirkap there is a block of buildings known as Mahal (royal residence) from which about forty-three glass beads[c] of yellow and opaque blue colour have been recovered.

An excavation of a somewhat later date (i.e. 1944–45) at Sirkap[d] reveals four successive stages of settlements from the mid-first century B.C. to the second century A.D. The first dates from the middle of the first century B.C. to the beginning of the Christian era. The second represents the period from the beginning of the Christian era to 50 A.D., whereas the third from 50 A.D. to early second century A.D. The fourth covers the second century A.D. In determining the date of these phases the evidence of the dates of the coins recovered along with them was very helpful. This excavation exhibits no new specimens other than beads and bangles. The number of glass beads found is fifty-five with colours ranging from dark yellow to orange and also copper-red, blue, grey, white, green, purple, etc. They are generally opaque but at times translucent. The shapes are cylinder-circular, spherical, spheroid, hexagonal, barrel, circular, groove-collared, etc.

Besides beads, nineteen glass bangles excavated from the site are mostly of green or blue colour and are generally opaque and rarely translucent; they showed a white chalky coating, being the result of disintegration of the glass due to atmospheric and sub-soil conditions. They occur at all levels and are generally of a double-convex or single-convex section with blunted edges and no decoration.

Sirsukh,[e] the third city of Taxila, is situated further to the north-east on the farther side of the Lundinala. The fortifications of the city were probably built in the reign of Kanishka. The only spot inside the city where some excavations have been done lies between the more northerly of the two 'Pindora' mounds and the north-western half of the village of Tefkian.

A number of glass beads of blue, black and red colour have been unearthed from Pindora–Tefkian site, one of the modern villages of Sirsukh. From the temple of Jandial, a mound at Sirsukh, four glass beads of blue, red, opaque turquoise colour and a colourless one have been recovered. Besides, nineteen beads were recovered from the mound D at Jandial, having spherical, oblate, barrel, pendant and cylindrical shapes.

Of the numerous Buddhist remains in the southern half of the valley of Sind-Sagar-Doab, the oldest and most conspicuous is the imposing Dharmarajika Stupa, known locally as the 'Chir' or 'Split' Tope from the great cleft which former explorers

[a] Lal (Dr) (1), 22. [b] Marshall (3), I, 204, 207. [c] Marshall (3), I, 207.
[d] Ghosh (A) (1), 45; 72–74. [e] Marshall (3), I, 4; 218–19; 220; 224; 228.

made through its centre. The foundation of Dharmarajika Stupa, it is stated, was not earlier than the time of Asoka and not later than about the middle of the 1st century B.C.[a]

One hundred and sixty beads[b] of black, blue, opaque, red, white, opaque white, yellow, and other colours as well as colourless glass having spherical, cylindrical, tetrahedral, long barrel, bell-like, pendant, vase-like and other shapes were recovered from the Dharmarajika Stupa.

In the chamber F1, as found by John Marshall, there was a floor of glass tiles[c] of bright azure blue colour mixed with a few others of black, white and yellow colour. These tiles, according to Marshall, are the same as those that have been unearthed in the procession path of the Great Stupa. These were most probably brought from the same path to pave this chamber during the time the flooring of the chamber had fallen in disrepair. Similar tiles were found in Chapel A1 at Kalawan, which, according to Marshall, might have also been transferred from the procession path of the Dharmarajika Stupa.

Regarding the datings of these tiles of Chapel A1 and of the Chamber F1, it is evident that they were not laid in the floor until a relatively late date, probably the fourth and fifth century A.D. These tiles are 10.25 in. square × 1.12 in. thick and are of transparent glass.

Besides these, glass beads of various colours and shapes have also been recovered from different minor sites of the Dharmarajika Stupa. Black glass, which looks very much like obsidian,[d] seems to have been manufactured at Taxila from a very early period and there are several examples of black bangles which have been found in the Bhir Mound, Sirkap and later sites.

Two plano-convex objects of blue glass, which are described as lenses, are not worked with any spherical cube. Even though they are polished on the flat surface, it is difficult to decide if they could have served the purpose of lenses. According to Beck, they resemble the Roman lenses both in size and thickness. Marshall believed these to be ornamental encrustations.[e]

Among the miscellaneous objects, there are examples of a number of sealings, intaglios, discs, ear-plugs, and finger-rings.

TER

The excavation at Ter[f] was carried out on the banks of the Terna, 12 miles north-east of Osmanabad, by the Archaeological Department, Government of Bombay, under Dr. J. M. Joshi. From the presence of the Northern Black Polished ware and Gupta terracottas in the lower and upper levels respectively it is assumed that the site had been under occupation from the fourth century B.C. to fourth century A.D. Among other antiquities mention may be made of glass beads, bangles, shell, terracotta, copper coins, iron objects like lamps, etc.

The Director of Archives and Museums of Maharashtra state also resumed

[a] Marshall (3), I, 236. [b] Marshall (3), I, 243. [c] Marshall (3), I, 247.
[d] Marshall (3), II, 684. [e] Marshall (3), II, 690; Beck (4), 23.
[f] *IAR* (1967–68).

excavation at Ter,[a] revealing the cultural sequence from pre-Mauryan to modern times. Antiquities comprised terracotta, kaolin, figures with typical ornaments and hair-dress, terracotta lamps, bangles, ear-rings, Roman clay bullae, and a Roman glass bottle of the Mediterranean type. Some typical examples of Sātavāhana glass were analysed by Dr. Tornati, of Stazione Sperimentale del Vetro, at Murano (vide chemical analysis).

TILWARA

The village of Tilwara (25°52′ N., 72°50′ E.) is located on the left bank of the Luni river, about 16 km south-west of the town of Oalatra. The excavation at this microlithic site in Tilwara[b] district or Barmer was conducted by a joint expedition of the Deccan College Post-Graduate and Research Institute, Poona and the State Department of Archaeology, with some collaboration of the Institute of the University of Heidelberg. Bits of shapeless iron, stray fragments of glass bangles and fragments of a shell bangle occurred in the upper level.

TIRUKKAMBULIYUR

It is situated on the banks of the Cauvery river 53 miles west of Tiruchchirapalli on the road to Karur. The excavation of the site[c] was undertaken by the Department of Ancient History and Archaeology of the University of Madras. It was characterized by three successive periods. Glass beads in association with fine red-slipped ware of various shapes, shell bangles and iron objects were found in the later level of period I. Period II was characterized by glass beads and glass, along with the emergence and wide use of red paste, semi-precious stones and a few copper coins. Period II was also distinguished by slipped and unslipped pottery, glass beads, glass bangles, etc.

TRIPURI

About thirty-one glass beads of various colours and shapes have been found at Tripuri[d] from stratum IV (100 B.C. to 200 A.D.) and stratum V (200 to 400 A.D.). They are blue, green, red, violet, black, devitrified orange-red, gold-foiled, and groove-collared, lug, melon-shaped, gadrooned, square-cylindered, bud-shaped, etc.

UJJAIN

The excavation at Ujjain,[e] in Central India, yielded a number of glass beads, ear-reels and bangles belonging to the period *c.* 500 B.C. to 1st century A.D. Of the few ear-reels, the most interesting feature on one specimen is the decoration of impressed coils representing 'eyes'; the decoration appears on one side only, being apparently meant for the onlooker. Dr. N. R. Banerjee[f] is of opinion that this disc has the refractive brightness of a mirror. Besides, a squarish seal, fully resembling one specimen from Maheswar, is of black glass with a green tinge and bears on one side the symbol of an elephant. The specimen appears to be of 300 B.C.

[a] *IAR* (1967–68), 35. [b] *IAR* (1967–68), 39, 41. [c] *IAR* (1961–62), 28.
[d] Dikshit (6), 90–91. [e] *IAR* (1956–57), 27; (1957–58), 36. [f] Banerjee, 206.

VADNAGAR

Spherical beads and red-polished wares are said to have been unearthed from Vadnagar[a] (Kshatrapa–Gupta site) in Mehsana district of Gujarat.

VAISALI

The excavation at Vaisali[b] in the district of Muzaffarpur was carried out from 1959 by K. P. Jaysawal Research Institute, Patna, under the supervision of Sri Sita Ram Roy. During 1960–61 the excavation was made at two sites, namely Baniya and Virpur, of which the latter was a new site. Excavation at the new area revealed three periods of occupation, of which period III exhibited glass bangles in association with terracotta human and animal figurines, beads, toy-cart wheel, etc. The date of the occupation of other sites seems to have begun from the second century B.C.

Tables XV and XVI furnish a synoptic survey of the varieties of excavated glass specimens, discussed in this chapter.

[a] *IAR* (1953–54), 10. [b] *IAR* (1961–62), 7.

TABLE XV

Varieties of glass objects, recovered from different excavated sites

Shape	*Colour*
1. Beads (1000 B.C.—1800 A.D.)	
Short tabular, barrel, square barrel, lug collared barrel, barrel, globular, spherical, spherical with etched oblate hexagonal, hexagonal barrel, hexagonal biconal, cylindrical (long and short), cylindrical square, flattened, cornerless cube, circular, short oblate-circular, short barrel-circular, lenticular with lug-collars, double chamfered cylinder, square, square-hexagonal, square-long cylinder, square cylinder with concave ends, spheroid, pear-shaped, truncated, truncated-circular, truncated barrel, short truncated bicone, square truncated barrel, bicone, bicone-circular, collared, collared short barrel, collared tablet barrel, collared cylinder, collared flat barrel, long barrel-groove-collared, disc, cylinder-disc, fluted, biconal, bicone collared, gadrooned with lug collars, gadrooned cylinder, gadrooned short barrel, elongated, lozenge-shaped, perforated, triangular, flat, tapered longitudinal, eye-bead elliptical, drum-shaped, prismatic square, irregularly circular, conical, grooved circular, long convex, tabular, segmented, segmented gadrooned, annular, onion-shaped, tube-shaped, plano-conical, plano-convex-circular, scaraboid, spacer, multi-spiral, pendant (triangular, bud, facetted, ball), club-shaped pendant.	*Blue*: deep and light, blue-green, blue-millefiori, blue-ultramarine, turquoise, cobalt, persian, sky-blue, azure-blue, greyish blue. *Green*: leaf and dull green, persian green, turquoise-green, royal-green, light hooker's green, sap-green, emerald-green, pale green, translucent. *Red*: Copper-red, Indian red, brilliant red, red chocolate, pomegranate, coral red, violet, shallac red. *Yellow*: lemon yellow, yellowish green, yellow ochre, buff-lemon, raw sienna, chrome-yellow, gamboge yellow, yellow matrix with green coating, yellow resembling sulphur, beads with lemon-yellow matrix; white, black and white, gold-foil, dark red, bright red with white core, grey, brown, snuffy brown, pale brown, ash-white, amber.
2. Bangles (1100 B.C.—1800 A.D.)	
Plano-convex, triangular section, thin or medium, solid, round, thick, semi-round, flat thick, round or flat with raised central ridge, broad with interlaced body, thick with grooves on circumference, semi-thick with angular rib, flat rib with diagonal beads, rectangular, circular, double-convex, oblong in section, flat on the inside and semi-cylindrical on the outside; oval, triangular with rounded apex, triangular with ridged apex, with straight sides and rounded edges; squarish section, three-arched rectangular with convex ends, double chestnut, pentagonal.	*Monochrome category:* milky white, black (opaque and translucent), jet black, grey, deep brown, ochre coloured, amber, amethyst. *Green*: sea-green, dark green, light green, turquoise-green, hooker's green, sap-green, emerald-green, permanent green, dark olive green. *Blue*: turquoise blue, sky-blue, cobalt-blue, royal blue, deep blue, navy blue, persian ultramarine blue; *Red*: Indian red, scarlet, burnt sienna, vermilion, raw sienna, golden red, honey-coloured, chocolate, deep chocolate, cream, red (opaque). *Yellow*: lemon yellow, yellow ochre, chrome yellow, gamboge-yellow, yellow (opaque), light yellow. *Polychrome category*: bluish (translucent), green with green and yellow oblique patches, greenish blue, yellow-brown, yellow and green.

3. Vessels and flasks (2nd–17th century A.D.)

Shape	*Colour*
Flasks (8 in number of about 1690 A.D in Ahmednagar). Flattened on the sides with a semi-circular or round body and a tall cylindrical neck; their height range between 27 to 34 cm; an omphalos or depressed kick in base and a beaded rim at the top; the bases vary from 12 to 14 cm in their width and the longest tapering neck in one instance is about 27 cm.	The flasks are of green and greenish blue.
Fragments of bowls (Amreli, in Kathiawar). Loop-handle of a bowl or a cup; fragments of rims of two bowls—one sub-triangular in shape.	Opaque and dull opaque white glass; pinkish.
Fragments of four or five bowls (Arikamedu—i.e. 1st century B.C.–2nd century A.D). Fragments of a pillar-moulded bowl.	Whitish iridescent glass of blue colour.
Complete bowl (*c.* 400 A.D.) A complete bowl having a globular belly with vertical ribbings all over the body and a short neck with an out-turned rim, covered with an iridescent patina, now peeled off; it appears to have been blown in a mould along with air-bubbles	The thin pale greenish blue tinge wall of the bowl seems to be highly transparent.
Fragments of the neck of a bottle from Devnimori (Sabarkantha)— (a) the largest piece was about 1″ in length, about $\frac{1}{2}$″ in height and about $\frac{1}{16}$″ in thickness. (b) a fine petal-shaped flat glass partially devitrified and having a very rough surface. (c) a rim of a bowl (of clear transparent glass) cut on the wheel to give it a slightly oblique profile (dated about 3rd to 5th century A.D.).	Fragments of the neck of a bottle of deep blue colour (the colouring agent, copper).
Fragments of twelve uniformly thin-sided glass vessels from Nevasa (*c.* 150 B.C.–200 A.D.)	Emerald green, Persian blue.
Three complete conical-shaped vessels from Taxila.	Light green flask of sea- or jade-green colour.
Roman glass bottle of the Mediterranean type from Ter.	

Miscellaneous objects

Shape	*Colour*
Large number of glass rods—rods range from 2 to 2.4 cm in length with a few specimens of larger dimensions, the longest being 4.6 cm, and have fine threading holes. They are long cylindrical circular.	
Finger-ring—	
I. Simple monochrome—(i) thin, round in section.	Black, yellow, pale brown, bluish green, light-green.
II. Simple monochrome but the circumference corrugated.	Yellow, red, green, blue.
III. Polychrome.	Black, green, red and blue (monochrome type).
Rings (Nevasa) both monochrome and polychrome—plano-convex, triangular and round.	Persian green, burnt sienna, sap green, light grey and ultra-marine blue (polychrome).
Slag pieces—cylindrical.	Jet black, green, yellow-green.
Discs (two unbroken and two fragmentary). Complete specimens—pulley-shaped, 36 cm in diameter, 15 mm in thickness. Grooved around the circumference.	Jet black, grey, black, red, copper-green.
Discs (Nasik) with a groove at the thickness of the circumference.	Light blue, white, vermilion or olive red.
Seal—squarish piece.	Black.
Tablet with its two edges raised up.	Dark.

TABLE XVI

Excavated sites	*Specimens*
Adamgarh, District Hoshangabad	Pieces of glass and bangles.
Ahar	Beads (5 in number). *Shape*: Short tabular, barrel and globular. *Colour*: Plain translucent variety; tabular cuprous and opaque green. Bangles (4 pieces). *Shape*: Plano-convex, triangular section. *Colour*: Monochrome category: turquoise blue, sea-green and milky white.
Ahicchatra	Beads (more than one hundred—1st century A.D.). *Shape*: Spherical, oblate, hexagonal forms (barrel, cylinder and flattened), cornerless cubes and circular, lenticular beads with lug-collars, double chamfered cylinder, square in section, lenticular. *Colour*: Opaque black, black and white, gold-foil, opaque red, dark red, bright red with white core. *Blue*: deep and light, blue-green, blue millefiori, opaque orange. *Green*: leaf and dull green and transparent.
Ahmednagar, Maharashtra State	Flasks (8 in number—about 1690 A.D.). *Shape*: Flattened on the sides with a semi-circular or round body and a tall cylindrical neck; their heights range between 27 to 34 cm; an omphalos or depressed kick in base and a beaded rim at the top; the bases vary from 12 to 14 cm in their width and the longest tapering neck in one instance is about 24 cm. *Colour:* Green and greenish blue.
Alagarai (northern bank of the Kaveri), District Tiruchchirapalli	Glass beads and glass bangles.
Alamgirpur	Glass beads (*c.* 1000 B.C.).
Amreli, in Kathiawar	Fragments of bowls. *Shapes*: Loop-handle of a bowl or a cup. Fragments of rims of two bowls—(one) sub-triangular in shape. *Colours*: Opaque and dull opaque white glass; pinkish.
Antichak, District Bhagalpur	Pieces of glass (1300–1500 A D.). *Colour*: Green.
Arikamedu, near Pondicherry (1st century B.C.—2nd century A.D.)	Beads. *Shapes*: Spherical spheroid, pear-shaped, cylindrical, barrel truncated, bicone, oblate and collared. Some of them may be sub-divided into sub-types, such as circular square, hexagonal, etc. according to their cross-sections. *Colours*: Blue, green, copper-red, white, black, yellow, violet, brown, grey (opaque and translucent).

Excavated sites	*Specimens*
Arikamedu (*contd.*)	Fragments of four or five bowls. *Shapes*: Fragments of pillar-moulded bowl. *Colours*: Whitish iridescent glass of blue colour. Miscellaneous objects: Rods of glass-like materials (large number) *Shapes*: Most of the rods range from 2 cm to 2.4 cm in length with a few specimens of larger dimensions, the longest being 4.6 cm and have fine threading holes. They have been described as long cylindrical circular glass beads. Some are solid without any holes. *Colours*: Olive green, bottle green, cobalt blue, greenish blue, brick- and liver-red. Some show a whitish deposit on the surface. Most of them are opaque and a few are transparent.
Azamgarh (Allahabad, Faizabad, Ghazipur and Varanasi)	Glass bangles.
Bagor, District Bhilwara	Glass beads.
Bangarh	Beads (1st century A.D.). *Shape*: Oblate. *Colour*: Blue.
Bhita	Beads (150 in number). *Colours*: Blue, azure blue and black (1st–5th century A D.).
Brahmagiri and Chandravalli	Beads (five in number). *Shapes*: Short barrel-circular, short oblate-circular, spheroid, long barrel-groove-collared. *Colours*: Deep and light green (translucent and opaque), green (opaque), sky-blue (opaque). Bangles (very few in number). *Shapes*: Plano-convex in section, triangular in section. *Colours*: Black, translucent light green and sky-blue.
Brahmanabad, Sind	Complete bowl (*c.* 400 A.D.—now preserved in the Prince of Wales Museum). *Shape*: A complete bowl having a globular belly with vertical ribbings all over the body and a short neck with an out-turned rim, covered with an iridescent patina, now peeled off; it appears to have been blown in a mould along with air-bubbles. *Colour*: Thin pale greenish blue tinge. The wall of the bowl seems to be highly transparent.
Brahmapuri (Kolhapur)	Beads (694 in number). *Shapes*: Spheroid, cylindrical, barrel, disc, fluted, biconical, oblate, hexagonal, bicone collared, etc. *Colours*: Green; yellow-matrix with green coating, yellow resembling sulphur, gold-foil, blue, black, copper-red.

Excavated sites	*Specimens*
Brahmapuri (*contd.*)	Bangles (hundreds of pieces of glass bangles). *Shapes*: I. Monochrome type *Thin monochrome type* (a) Thin or medium monochrome, 'solid' translucent in the two 'layers'. (b) With very thin border. *Thick monochrome type* (a) Round thick monochrome, semi-round. (b) Flat thick monochrome. (c) Thick and rounded, bluish green with green and yellow oblique patches between yellow bands. (d) Broad with concentric rings of different colours and beaded circumference. (e) Thin, consisting of two layers; the upper is very thin in oblique bands. (f) Semi-thick with grooves on circumference marked by oblique beads. (g) Thin or very thin with appliqué design on monochrome body. *Colours*: Monochrome type: black, yellow, green, dark green, brown, navy-blue, light greenish blue. Polychrome type: green or brown, yellow-brown, yellow and green, bluish green with green and yellow patches, bluish (transparent). Finger-ring (several specimens). *Shapes*: I. Simple monochrome (a) Thin, round in section. (b) Thick and convex in section. II. Simple monochrome but the circumference corrugated. III. Polychrome. *Colours*: Monochrome type: black, yellow, pale brown, bluish green, light green. Polychrome type: yellow, red, green, blue and yellow.
Broach	Bangles (3rd century B.C.).
Chandraketugarh, District 24 Parganas	Beads (1st century A.D.).
Charsada, ancient Pushkalavati, capital of Gandhar	Bangles (several bangles of stratified glass). *Shapes*: One with angular ribs; another with flat ribs with diagonal beads.
Devnimori, District Sabarkantha	Hollow cylindrical objects of blue glass.
Devnimori stupa, near Shamlaji in North Gujarat	Bowls. *Shapes*: Fragments of the neck of a bottle of deep blue colour (copper, the colouring agent); the largest piece was about 1″ in length, about $\frac{1}{2}$″ in height and about $\frac{1}{10}$″ in thickness. A fine petal-shaped flat glass partially devitrified and

Excavated sites	*Specimens*
Devnimori stupa (*contd.*)	having a very rough surface. A rim of a bowl (of clear transparent glass) cut on the wheel to give it a slightly oblique profile (dated about 3rd to 5th century A.D.).
Dharanikota, District Guntur	Glass objects of varying shapes and colours; an assortment of glass objects.
Eran (ancient Airikina), District Sagar	Beads (1st–5th century A.D.). Bangles (16th–18th century A.D.).
Hastinapur & other explorations	Beads (18 beads, of which 10 are fragmentary). *Shapes*: Spherical with etched, long or short cylinder and circular. *Colours*: Green, black and deep blue (some opaque). Bangles: Largest in number; most of these are opaque but some are translucent. *Shapes*: Triangular in section, rectangular, circular, double-convex, oblong in section. *Colours*: Brownish, black (opaque and translucent) deep blue and green.
Hemmige, District Mysore	Beads and bangles.
Kanchipuram, District Chingleput	Beads and bangles (of medieval period).
Karad	Beads: Gadrooned beads of blue glass with lug collars, gold-foil
Kesarpalli in the Guntur district	A few glass beads
Kopia, near Basti, U.P.	Beads (innumerable, of 5th century B.C.). *Shapes*: Diameter about 1.5 mm to 3 mm, tabular, elongated, lozenge-shaped, perforated, spherical, barrel, round, triangular, square-hexagonal, flat, tapered longitudinally, etc. *Colours*: Yellow, blue, black, greenish blue, greyish blue, pale greenish yellow, coral red, opaque white, colourless transparent. Bangles: Fragments of bangles. *Shape*: Flat on the inside and semi-cylindrical on the outside.
Koundinyapura	Beads (10 in number). *Shape*: Eye-bead (mainly). *Colour*: Cane glass of opaque copper-red colour. Miscellaneous objects: (i) Ear-plug. *Shape*: Ear-plug with a heavy patina. *Colours*: Black, green, vermilion. (ii) Ear-reel. *Shape*: Ear-reel with flat sides and concave walls for the lobes.

Excavated sites	*Specimens*
Koundinyapura (*contd.*)	(iii) Discs. *Shape*: Discs with thinner and slightly oblique walls.
Kumrahar	Beads (26 in number). *Shapes*: Hexagonal, spherical, cylindrical, elliptical, drum-shaped, prismatic, square, etc. *Colours*: Green and blue (translucent opaque).
Kunattur, in the Chingleput district (in Megalithic context)	Beads (200 B.C.–200 A.D.).
Maheswar & Navdatoli:	
(a) Maheswar (400 B.C.–500 A.D.)	Beads (several fragmentary and 11 intact specimens). *Shapes*. Spherical, truncated barrel, globular, hexagonal cylinder and irregularly circular. *Colours*: Deep blue, deep green, yellow, sea-green, soiled white and greyish black. Slag pieces (3 in number). *Shape*: Cylindrical slag-pieces. *Colours*: Jet black, green, yellow-green.
(b) Navdatoli, Madhya Bharat	Beads (4 in number). *Shapes*: Flat, circular, conical and globular. *Colours*: Green, ash-white, dark blue. Bangles (673 in number—both monochrome and polychrome at Navdatoli and Maheswar, of which fifty-three pieces of monochrome bangles from Navdatoli and thirty-four pieces of polychrome bangles from Maheswar and two from Navdatoli). *Shapes*: *Monochrome type:* plano-convex, triangular, round, oval, triangular with rounded apex, triangular with ridged apex with straight sides and rounded edge. *Colours*: *Monochrome type:* green, yellow, red, purple and black. With various combinations and shades: turquoise green, sap-green, hooker's green, dark and purple, honey-coloured Indian-red, cobalt blue, ultramarine blue, turquoise blue, deep chocolate, cream and lemon yellow. *Polychrome type:* Indian-red, jet black, lemon yellow, chrome orange, light yellow, dark olive green, hooker's green, light cream, sap-green, turquoise blue and chocolate. Miscellaneous objects: (i) Discs (2 complete and 2 fragmentary). *Shapes*: Pulley-shaped complete specimens—36 cm in diameter, 15 cm in thickness; groove around the circumference. *Colours*: Jet black, grey, black, red, copper-green. (ii) Seal (1 seal with elephant impression). *Shape*: Squarish piece. *Colour*: Black.

Excavated sites	*Specimens*
Navdatoli (*contd.*)	(iii) Tablet (1 in number). *Shape*: A tablet, with its two edges raised, indicating that the impressions were stamped when the glass was in plastic state. *Colour*: Dark.
Maski, in Mysore State (1000 B.C -1600 A.D.).	Beads (45 in number). *Shapes*: Standard cylinder, barrel, circular, bicone truncated circular, bicone circular, spherical, long cylinder grooved circular, long convex circular, long cylinder circular. *Colours*: Blue, green, black, yellow, white, amber, shellac red. Bangles (14 incomplete specimens). *Colours*: Sea-green, turquoise green, amber, red, blue and yellow.
Mason, District Ghazipur	Circular objects.
Nagar, District Kaira	Beads (1st–9th century A.D.).
Nasik and Jorwe	Beads (7 in number). *Shapes*: Low truncated barrel, globular, tabular. *Colours*: Green, blue and gold-foil. Bangles (19 fragmentary pieces). *Shapes*: Monochrome type: triangular section, plano-convex, squarish section. *Colours*: Black, yellow, orange, chocolate, blue, green, purple, white; monochrome and polychrome, opaque and translucent. Miscellaneous objects (33 in number) Discs (5 in number). *Shapes*: Disc-shaped (5 complete specimens) with a groove at the thickness of the circumference. *Colours*: Light blue, white, vermilion or liver-red.
Nevasa, on the Pravara, major tributary of the Godavari; District Ahmadnagar	Beads (348 in number—150 B.C.–1700 A.D.). *Shapes*: Collared short barrel, globular, small barrel, square barrel, short truncated barrel, short cylinder, tabular, collared tablet barrel, short truncated bicone, collared flat barrel, square cylinder with concave ends, segmented, segmented gadrooned, square truncated barrel, hexagonal biconal, annular, onion-shaped, collared cylinder, gadrooned globular, gadrooned short cylinder, gadrooned short barrel, lug-collared barrel, cylinder disc, irregularly circular. *Colours*: Beads with gold-foil, with lemon-yellow-matrix; black; green—persian-green, turquoise-green, royal-green, light hooker's green, sap-green, emerald-green; red—Indian-red, copper-red, brilliant red, red chocolate, pomegranate-coloured, snuffy-brown-coloured; grey;

Excavated sites — *Specimens*

Nevasa (*contd.*)

blue—ultramarine, turquoise, cobalt, persian; yellow—lemon yellow, yellowish green, yellow ochre, buff-lemon, raw sienna, chrome-yellow, gamboge yellow; white, purple, etc.

Bangles: both monochrome and polychrome types.
Monochrome: 504 in number—50 B.C.–1700 A.D.
Polychrome: 81 in number—1400–1700 A.D.
Shapes: Plano-convex, triangular, channel, square, circular, three-arched rectangular with convex ends, etc.
Colours: Monochrome type: blue: persian, ultramarine, royal; yellow (opaque), black (opaque), green; blue; red (opaque)—scarlet, burnt-sienna, vermilion, raw sienna; yellow—lemon-yellow, yellow-green, yellow-ochre, buff-lemon, raw-sienna, chrome-yellow, gamboge-yellow; green—sap-green, hooker's green, emerald-green, permanent green, turquoise-green; blue—ultramarine and persian blue.
Polychrome type: yellow—lemon, gamboge, chrome, golden, red—scarlet, burnt sienna, vermilion, raw-sienna; black; green—permanent and sap-emerald green; blue—royal and ultramarine blue.

Miscellaneous objects:
Rings (26 in number) both monochrome (150 B.C.–50 B.C.) and polychrome (1400–1700 A.D.).
Shapes: Plano-convex, triangular and round.
Colours: Monochrome type: basically in four colours—black, green, red and blue. Most of these are opaque.
Polychrome type: principal colours—persian green, burnt sienna, sap-green, light grey and ultramarine blue.

Small glass vessels.

Rim. Fragments of 12 opaque glass vessels (150 B.C.–200 A.D.).
Shape: Uniformly thin-sided.
Colours: Principal colours—emerald-green, persian blue.

Kohl stick (1 fragmentary piece of a rod—50 B.C.–200 A.D.).
Shape: Flat-topped cylindrical.
Colour: Royal blue.

Glass slags (14 in number).
8 slags (150 B.C.).
5 slags (50 B C.–200 A.D.).
1 slag (150 B.C.–50 B C.).

Twisted waste glass pieces, bangles etc. (15th–18th century A.D).

Paiyampalli, District North Arcot

Bangles and beads (according to carbon dating 315 ± 100 B.C.).

Piklihal, near Raichur Doab, Andhra Pradesh

Pieces of bangles, both monochrome and polychrome type.
Shape: Wound process, double chestnut.
Colours: Dark, green, yellow, grey, deep brown, ochre-coloured.

Excavated sites	*Specimens*
Patna (the well-known sites, namely Kumrahar and Bulandibagh)	Five positive sealings, excavated between 1914 and 1926 (attributed to 300–200 B.C.). (1) Sealing of crude blue glass, belonging to pre-Mauryan period. Diameter nearly $\frac{3}{4}$″, thickness $\frac{1}{8}$″, sp. gr. 1 71. Specimen found at Bulandibagh by Ghosh and deposited at Patna Museum. (2) Sealing of greenish glass (*c.* 250 B.C.). Circular in shape. Diameter about $\frac{1}{2}$″. Found at Bulandibagh by Ghosh and deposited at Patna Museum. (3) Oval-shaped transparent glass disc with greenish tinge (*c.* 200 B C.) Diameter $\frac{5}{8}$″ × $\frac{1}{2}$″, thickness $\frac{1}{2}$″, sp. gr. 1.71. Found at Kumrahar by Spooner in 1914–15 and deposited at Patna Museum. (4) Clear transparent rectangular glass disc with a greenish tinge and having slightly bulging sides (*c.* 200 B.C.). Size: $\frac{5}{8}$″ × $\frac{5}{8}$″ × $\frac{1}{8}$″. Sp. gr.: 1.71. Found by Dr. Spooner in 1916 at Kumrahar and deposited at Patna Museum. (5) Blue glass or transparent circular glass disc with a bluish tinge (*c.* 200 B.C.). Diameter $\frac{9}{16}$″. Thickness $\frac{1}{8}$″. Sp. gr. 1.78. Found by Spooner in 1916 at Bulandibagh and deposited at Patna Museum.
Prabhas Patan, Gujarat	One bangle and 10 beads, belonging to 3rd and 4th century A.D.
Prakash	Beads (19 in number). *Shapes*: Gadrooned, club-shaped pendant, barrel, spherical cylinder, circular, standard convex, cylinder square. *Colours*: Opaque-yellow, translucent or opaque green; blue, black (multi-coloured design). Bangles (45 in number). *Shapes*: Pentagonal, circular section, rectangular, plano-convex section. *Colours*: Black, green, light-green, blue, opaque blue, bichrome and polychrome translucent and opaque.
Rairh	Glass beads of good quality. A bead of very rare shape with square in profile and with a small incision to form a *swastika* (3rd century B.C.– 2nd century A.D.).
Rajgir	Glass beads.
Rajghat, District Varanasi	Beads (4th–6th century A.D.). Bangles (1st–4th century A.D.). Bangles of polychrome type (14th–17th century A.D.). Glass pendants (300–700 A.D.).
Rangmahal, Bikaner, Rajputana	Beads (9 in number). *Shapes*: Gold-foil, oblate-shaped, tube-shaped. *Colours*: Blue, green, white, pale matrix.

Excavated sites	*Specimens*
Rangmahal (*contd.*)	Bangles (end of 2nd to 3rd century A.D.). *Colours*: Two fragments of glass bangles of black and blue colours.
Ratnagiri, District Cuttack	Pieces of glass.
Rupar, in Ambala district	Glass beads and bangles associated with painted grey ware (Rupar, period II).
Sambhar (near the salt lake)	Detailed particulars are not available for all the stratified finds. One iridescent frog-shaped amulet of white glass belonging to Kushana level.
Satara district	Glass bangles.
Sirpur	Bangles (7th–8th century A.D.). *Shape and Colour*: Bangles both flattish and triangular in section are found in large numbers and are generally of the monochrome variety. Both thicker and thinner types of glass rods were used for making bangles. In the former case, extraordinarily amber and brandy-coloured thick rods (2.3 cm thickness) were used; whereas in latter case, a thin ribbon of dark blue glass was used as base plate. Over this was placed a rod of dull opaque green-blue glass, producing an irregular rope-like pattern.
Sohagaura, District Gorakhpur	Glass bangles (stratified and polychrome type), glass beads and studs.
Sonepur, District Gaya	Glass beads, associated with Northern Black Polished wares.
Sravasti	Black beads with white lines (2nd–1st century B.C.).
Sopara	In the casket along with the relics of Buddha was found a large perfectly cylinder-shaped hexagonal piece of deep blue glass and a small bead of red glass (*c.* 188–190 A.D.). The first excavation of the stupa at Sopara was made by Bhagwanlal Indraji in 1886. Another specimen is a small bottle of translucent blue glass, about 2″ in height with an ovoid body and a tall cylindrical neck. This small bottle of glass has been recovered in a resumed excavation at the same site in 1941.
Sulur, in Coimbatore district. Glass beads have been found both in the megalithic tombs and in the middens around them.	Beads: Three varieties of beads have been found in the Megalithic tombs at Sulur: (1) whitish glass with a specific gravity of about 3.43; (2) barrel circular beads of blue glass with white oblique strokes in the middle; (3) a cuprous oxide red bead (turned into pale brown colour) with large air bubbles and a corroded surface. Beads (148 in number) have also been recovered from the middens near the megaliths at Sulur. They are of green (72), red (29), black (11), blue (24), blue zen (1), yellow (3), opaque

Excavated sites — *Specimens*

Sulur (*contd.*)

orange (1), imitation garnet (2), pale brown (1), white (1), clear glass (2), corroded glass (1). Glass in the megalithic tombs near Sulur in Coimbatore district was first noticed by Col. Tucker.

Taxila

Beads (3,697 in number).
Shapes: Eye-bead, plano-conical, scaraboid, spacer, plano-convex-circular, pear-shaped, multi-spiral, hexagonal, barrel, tubular, hexagonal-bicone, square, barrel, corner-less cube, club-shaped, pendant, triangular pendant, bud pendant, square facetted pendant, ball pendant.

Bangles (fragments, 232 in number).
Shapes: Circle and plano-convex form—various shapes.
Colours: Blue (pale to dark), sea-green, amber, violet, black, yellow, brown, amethyst.

Vessels (3 complete vessels).
Shape: Conical flask.
Colours: Light green flask of sea- or jade-green colour

Miscellaneous objects:
(i) Tiles:
Shapes: About 10¼″ square and ⅛″ in thickness.
Colours: Greenish blue, bright azure blue, black-white, yellow.

(ii) Sealings (3 in number).
Shapes: Circular in shape with a diameter of 0.62″ (Śaka-Parthian level).
Colours: Greenish white.

(iii) Intaglios (2 in number—1st century A.D.).
Shapes: Oval in shape.
Colours: Composite glass in shades of green, white and blue.

(iv) Discs (4 in number—Śaka-Parthian level).
Shapes: Convex in shape, about 1.2 cm in diameter.
Colours: Variegated glass, partly coloured and partly colourless.

(v) Ear-plug (1 in number). A dumb-bell shaped object of solid blue-green glass.

(vi) Lens (?) (2 in number).
Shapes: Two plano-convex objects of blue glass which are described as lenses, but are not worked with any spherical cube. Even though they bear polish on the flat surface, it is difficult to decide if they could have served the purpose of lenses. According to Beck they resembled the Roman lenses both in size and thickness. Marshall thought these to be ornaments or encrustation.

(vii) Finger-rings (3 fragments—1st century A.D.).
Shape: Flat almond-shaped bazel; moulded.
Colours: Clear transparent glass, yellow and composite glass with blue and green colour.

Excavated sites	*Specimens*
Ter, District Osmanabad	A Roman glass bottle of the Mediterranean type.
Tilwara district	Stray fragments of glass bangles.
Tripuri	Glass lumps and beads of different colours—blue, green, red, violet and black (300 B.C.–400 A.D.).
Trirukkambuliyur, District Tiruchchirapalli	Glass beads and bangles.
Ujjain	Ear-reels, beads, bangles, etc. (1st century A.D.).
Vadnagar, in Mehsana district of Gujarat	One special glass bead having the design of a bird in a quadrant.
Vaisali, District Muzaffarpur	Glass bangles.

TABLE XVII

Chronology of Glass Specimens Excavated from Different Sites

Sites	1100–800 B.C.	7th–5th century B.C.	4th B.C.–1st century A.D.	2nd–5th century A.D.	6th–10th century A.D.	11th–18th century A.D.
HASTINAPUR	*Phase II* Brownish and black bangles	*Phase III* Black beads →	Blue ← beads	*Phase IV* Black to deep blue beads		*Phase V* Bangles (opaque and translucent) —brown, black green, etc.
MASKI	*Phase I* Cylinder circular beads →	Blue, green, black beads →	*Phase II* Blue, green, black, yellow, white ← beads	*Phase III* Blue, green, white, amber, shellac red beads		*Phase IV* Fragmentary polychrome bangles
RUPAR	*P. G. Ware period* Bangles →	→	→			
ALAMGIRPUR	*P. G. Ware period* Beads →	→	→			
TAXILA (a) Bhir Mound (b) Sirkap (c) Sirsukh (d) Dharmarajika Stupa		*Bhir Mound* *Stratum IV* Beads—blue, black, green, dark green, grey, opal, white, amber; ear-reel; fragment of a miniature casket	*Bhir Mound* *Stratum III* Beads—blue and green; yellow, red and turquoise *Stratum II* Bangles, beads, seals with blue, black and green colours *Stratum I* Spear-shaped pendant of green glass			

Table XVII (*contd.*)

Sites	1100–800 B.C.	7th–5th century B.C.	4th B.C.–1st century A.D.	2nd–5th century A.D.	6th–10th century A.D.	11th–18th century A.D.
Taxila (*contd.*)			*Sirkap* *Strata VI & V* Blue, yellow, black and red beads *Sirkap* *Strata IV, III & II* Bangles (pale and dark blue); beads (yellow, blue, green, amber, pale blue, etc.) *Sirsukh* Beads—blue, black, red, opaque, turquoise *Dharmarajika Stupa* Tiles—bright, azure-blue, black, white, yellow, etc.			
Arikamedu			*Northern Sector:* (a) Pre-Arretine; (b) Arretine; (c) Post-Arretine Shades of blue and green beads; a fragment ←	*Southern Sector:* (a) Pre-structural; (b) Early Phase; (c) Main Drain period; (d) Late Drain period;		

Table XVII (*contd.*)

Sites	1100–800 B.C.	7th–5th century B.C.	4th B.C.–1st century A.D.	2nd–5th century A.D.	6th–10th century A.D.	11th–18th century A.D.
ARIKAMEDU (*contd.*)			of a bowl of blue glass; a fragment of amber-coloured bangles	(e) Latest phase Pillar-moulded bowl of whitish iridescent glass		
AHMEDNAGAR						Eight flasks
ANTICHAK						*Phase II* Pieces of green glass
BHITA			←	Objects of various colours—blue, azure blue, black, green, etc.		
BRAHMAGIRI and CHANDRAVALLI			←	*Phase III* Andhra culture. Beads and bangles—sky-blue, light green, deep green		
BRAHMANABAD				A complete bowl—thin pale greenish blue in colour		

TABLE XVII (*contd.*)

Sites	1100–800 B.C.	7th–5th century B.C.	4th B.C.–1st century A.D.	2nd–5th century A.D.	6th–10th century A.D.	11th–18th century A.D.
BRAHMAPURI (KOLHAPUR)			*Phase IV* Fragmentary bangles of different shapes and colours ←	*Phase III* Fragmentary bangles of different shapes and colours		
BROACH			Beads with various colours			
CHANDRA-KETUGARH			←	*Phase IV* Beads		
DEVNIMORI				*Phase I* Fragment of blue glass *Phase II* A fine petal-shaped flat glass		
DHARANIKOTA			*Phase II* Glass objects of various shapes and colours			
ERAN				*Phase III* Beads and bangles		*Phase IV* Beads and bangles
KANCHIPURAM						*Period II* Beads and bangles

TABLE XVII (*contd.*)

Sites	1100–800 B.C.	7th–5th century B.C.	4th B.C.–1st century A.D.	2nd–5th century A.D.	6th–10th century A.D.	11th–18th century A.D.
KAUSAMBI			←	*Phase III* Beads of various shapes		
KOPIA		Innumerable glass beads and glass slags of various shapes and sizes				
KAUNDINYAPUR			*Phase III* Beads, ear-plug, bangles ←	*Phase IV* Beads		*Phase VI* Bangles of stratified type of glass
KUMRAHAR				*Phase III & IV* Green and blue beads		
MAHESWAR and NAVDATOLI			*Maheswar* *Phase III* Glass objects *Phase IV* A seal with elephant impression *Phase V* Beads and other objects → *Navdatoli* *Phase III* Beads—green, ashy-white, etc.	*Maheswar* *Phase VI* Beads of various colours		*Maheswar* *Phase VII* Beads

TABLE XVII (*contd.*)

Sites	1100–800 B.C.	7th–5th century B.C.	4th B.C.–1st century A.D.	2nd–1st century A.D.	6th–10th century A.D.	11th–18th century A.D.
NAGAR				*Phase III* Glass beads →		
NASIK and JORWE			*Nasik* *Phase II* Beads	*Nasik* *Phase III* Blotched beads. Polychrome and monochrome bangles		*Nasik* *Phase IV* Gold-foil beads
NEVASA			*Phase IV* Beads ←	*Phase V* Bubbleless blue glass; very thin blue bangles, monochrome and polychrome type, beads of various colours and shapes, rim fragments of vessels		*Phase VI* Large number of bangles with plano-convex triangular section
PRAKASH		←	*Phase II* Bangles ←	*Phase III* Polychrome → and bichrome types of bangles	*Phase IV* Large number of → black bangles, both polychrome and bichrome types	
RAIRH			Beads of very → good quality			

TABLE XVII (*contd.*)

Sites	1100–800 B.C.	7th–5th century B.C.	4th B.C.–1st century A.D.	2nd–5th century A.D.	6th–10th century A.D.	11th–18th century A.D.
RAJGHAT		*Phase I* Glass objects →	→	→		*Phase VI* Polychrome bangles
(a) Trench Excavation				*Trench Excavation Phase III* Glass ← pendants and bangles	*Trench Excavation Phase IV* Glass pendants and bangles	
SONPUR		*N.B.P. Wares* Glass beads				
SRAVASTI	P.G. Ware culture. → Green beads	→	Stratified glass			
SULUR			Large number of beads →	→		
TER			Beads →	→		
TRIPURI			*Stratum IV* Beads → green, red, violet	*Stratum V* Beads—devitrified orange-red, gold-foiled, groove-collared		
UJJAIN			Beads, bangles, ear-reels. A squarish seal of black glass with symbol of an elephant			

TABLE XVII (*contd.*)

Sites	1100–800 B.C.	7th–5th century B.C.	4th B.C.–1st century A.D.	2nd–5th century A.D.	6th–10th century A.D.	11th–18th century A.D.
VAISALI			Beads			
AHICCHATRA				Beads—black, blue, green, dark red, blue-green, orange (opaque)		
PAIYAMPALLI			Beads and bangles			
PATNA			Five glass seals of blue, green and greenish tinge			
RANGMAHAL			←	Pieces of bangles—black and blue colour		
SIRPUR					Bangles—amber and brandy coloured with various designs	
SOPARA				Beads—red and deep blue colour		
PRABHAS PATAN				Bangles and beads		

CHAPTER III

SCIENTIFIC STUDIES AND PHYSICO-CHEMICAL ANALYSES OF INDIAN GLASS SPECIMENS, RAW MATERIALS AND SOURCES

Modern methods of studying ancient glass samples, analysing such samples by refined physico-chemical techniques and their importance in understanding ancient techniques and processes in the absence of recorded literary guides have been discussed and emphasized in chapter I. It is needless to say that, compared to the already available wealth of ancient glass specimens unearthed by the archaeologist's spade, such scientific studies have so far been very inadequate. A good deal of attention has been given to superficial examination of glass objects and classifying them according to their uses, shapes, colours and various artistic designs. The importance of glass as a medium for artistic expressions has been rightly recognized. Such studies, however, have been of little assistance in our understanding of an ancient technology through which other aspects of man's creative genius found expression.

PHYSICAL STUDIES

Regarding physical studies, Indian glass specimens have been subjected to microscopic examinations to reveal the existence or otherwise of bubbles and throw light on the temperature of furnaces, fritting and melting operations. In a number of samples, the hardness has been measured, and we have the specific gravity determinations in the case of quite a few. The specific gravity is easily determinable by the displacement method, by the method of flotation of grains in mixed liquids very suitable when the samples are available in small amounts, and by the pyknometer method. For glass, the specific gravity depends to some extent on its composition or rather the proportions of silica, lime and alkali mixtures and also on its past thermal history. Small differences varying from 0.006 to 0.011 have been found between well-annealed specimens and those which had been quickly cooled. A few hours' annealing at 200–300°C below the temperature of 'incipient flowage' is necessary for glass to reach its maximum density. Little is known of the density of glass beyond the softening point. Specific gravity values of a few ancient Indian glass samples and those of modern soda-lime-silica glass of different compositions are shown in Table XVIII. Values of a few ancient samples from other culture areas are also included for comparison. The specific gravity values of the Indian and foreign samples of ancient glass found from widely separated regions and differing widely in time are all fairly in agreement. Compared to compositions of modern soda-lime glass, some of the values are rather large. For Taxila samples, SiO_2 ranges between 67 to 71%, alkalies between 17 to 19% and CaO.MgO between 7 to 10%. For Kopia samples, the values are generally high with the exception of the refractory piece. Rajghat samples conform

TABLE XVIII

Specific Gravity of Ancient Indian and Foreign Glass Samples and those of Modern Soda-lime Glass

Ancient Indian samples		
Place and date	Sample	Sp. gr.
Hastinapur[a] (800–500 B.C.)	Brownish glass bangle	2.55
	Black glass	2.56
Taxila[b] (600–300 B.C.)	Bead	2.35
	Green glass	2.35
	Amber-coloured bead	2.40
	Vajra-shaped opal glass pendant	2.50
	Lace glass	2.51
	,, ,,	2.31
	Ribbed ware	2.66
Rajghat[c] (600–200 B.C.)	Translucent black bead	2.31
	Translucent blue green bead	2.39
	Translucent pale blue bead	2 37
	Transparent olive green bead	2.36
	Opaque reddish brown bead	2.44
Maheshwar[d] (300 B.C.)	Dark amber coloured	2.41
Kopia[e] (3rd cent. B C.–3rd cent. A.D.)	Perforated bead (quartz)	2.68
	Perforated rectangular bead	2.60
	Bangle fragment	2.51
	Broken piece in refractory vessel	2.53
	Refractory piece	2.33
Nasik[d] (300 B.C – 100 A D)	Transparent bottle green	2.684
	Bottle green glass splinter	2.352
	Thick bottle green glass	2.593
	Black glass (superficially weathered)	2.518

Samples from other culture areas[f]		
Place and date	Sample	Sp. gr. (20°C)
Luristan (*c.* 1000 B.C.)	Bead	2 49
Ur	Blue green bead	2 29
Constantinople (probably B.C. in date)	Eyebead	2.42
Europe or near East	Blue green	2.35
Cumae	Triangular bead	2.34
Near East	Biconical bead	2.23
Java	Roman style bead	2.55
Egypt	Bead	2.08
Persia	Bead	2.15
Loulan, Turkestan	Glass fragment	2.45
Loulan, Turkestan	Bead	2.17
Kharakhoto, Mongolia	Green bead	2.56
Mongolia	White bead	2.50
China	Eye-bead	2.24
China	Blue plaque	2.58
China	Blue green	2.66
China	Blue cone crescent	2.52

[a] Lal, 13, 23. [b] Beck (4); Dikshit (4), 7, 10, 28; Marshall (Taxila), II, 688–89. [c] Bharadwaj, 42–46. [d] Lal (Dr.) (2), 48–58. [e] Roy and Varshney, 366–68. [f] Caley, 39–46.

TABLE XVIII (*contd.*)
Specific Gravity of Ancient Indian and Foreign Glass Samples and those of Modern Soda-lime Glass

Ancient Indian samples			Modern Soda-lime glass[h]			
Place and date	Sample	Sp gr.	Composition			Sp. gr. (1206°C)
			SiO_2	Na_2O	CaO	
Arikamedu[g] (1st. cent. A.D.)	Blue glass bead	2.55	82.6	17 4	—	2 19
Bellary[d]			70.0	30.0	—	2.42
(14th–15th cent. A.D.)	Four glass bangles	2.42	60.0	40.0	—	2.28
		2.50	63.0	13.6	23.4	2.61
Kolhapur[d]			70.0	20.0	10.0	2.26
(14th–15th cent A.D.)	Four glass bangles	2 42	70.0	10.0	20.0	2 31
		2.50	72.25	15.1	12.1	2.28
			73.5	16.5	10	2 31

[g] Subramanian, 19–20. [h] Thorpe's *Dictionary of Applied Chemistry*, V, 4th. ed., 542.

more or less to the value of 2.31 for modern soda-lime glass of composition SiO_2-Na_2O-CaO: 70–10–20. The Constantinople eye-bead (B.C. in date) of sp. gr. 2.42 has the composition: SiO_2–Na_2(+ K_2O)–CaO: 68.2–19.3–7.2. For pre-Han and Han lead-barium glass beads, the sp. gr. values lie between 3.25 to 3.79. Some Chinese yellowish, greenish and brownish black lead glass figurines of 3rd to 4th centuries A.D. gave values as high as 5 00, 5.49 and 5.75.

CHEMICAL ANALYSES

We noticed in Chapter I that in Europe systematic chemical analyses of ancient glass objects started with Neumann and his co-workers from the middle of the twenties, although some good work of a scattered nature was done before them by Benrath, Roters, Parodi, Rathgen and a few others. In India, work in this field was seriously taken up by Sana Ullah, archaeological chemist, from the beginning of the twenties soon after the establishment of the Chemical Branch of the Archaeological Survey of India in 1917.[a] He analysed ancient glass samples collected from a number of archaeological sites which included Taxila, Nalanda, Assam, Kurukshetra, Rairh, Udayagiri and a few miscellaneous samples. Sana Ullah undertook these difficult and laborious gravimetric analyses before the results of systematic investigations of ancient glass by Neumann and his collaborators using improved techniques appeared. He had naturally to depend on methods followed by European workers in the first two decades of the present century, which naturally left much to be desired, and what he achieved in the circumstances need hardly be overestimated. Sana Ullah's good work was not followed up until after the beginning of the fifties when a band of new workers, in Government laboratories and elsewhere, came forward to take up

[a] Caley's statement: 'The first analysis of ancient Indian glass was reported by Subramanian', p. 50, is incorrect.

the scientific study and laborious chemical analyses of archaeological glass samples. This group included R. Subramanian, B. B. Lal, P. Roy, Y. P. Varshney, J. K. Ranade, Jhope and H. C. Bharadwaj. The results of their investigations are presented in Tables XIX and XX. It is also to be noted that this renewed interest in the scientific examination of archaeological objects coincided with the new enthusiasm witnessed in archaeological researches and the rich crop of objects, including glass, that came to light from several archaeological sites.

Mention must be made of the efforts of some foreign scholars and analysts who showed interest and analysed a few ancient Indian samples by the more recent techniques. Dr. M. Tornati of the Stazione Sperimentale del Vetro di Murano in Italy analysed some specimens from Arikamedu, Ter and Tripuri; A. Lamb, in the course of his studies of south-east Asian glass beads, analysed a few specimens from Arikamedu; we have already reported Sayre and Smith's work on 330 ancient glass samples, including a number of Indian specimens. The increasing emphasis on the determination of elements present in traces which escape normal gravimetric processes is clearly evident in these endeavours at overseas laboratories and is expected to attract the serious attention and efforts of glass analysts in India. In his introduction to Caley's admirable work on the analysis of ancient glasses from 1790 to 1957, Paul N Perrot, Director of the Corning Museum of Glass, has observed as follows:

> "Since the Second World War a new generation of glass scholars has arisen, new collections of international importance have developed, and the great public collections formed since the middle of the nineteenth century have been strengthened.
>
> "During this period the character of glass scholarship has greatly changed. An encyclopaedic approach has given way to a more specialized outlook, and an increasing awareness of the interdependence of styles and methods. It is now recognized that if glass scholarship is to be of lasting significance it must expand its basis, relate itself to the other main streams of human endeavour, and be supported by all the historical and scientific disciplines."
>
> *   *   *   *
>
> ". . . The whole arsenal of modern technology has been placed at the disposal of the glass scholar and methods which were undreamed of a mere ten years ago are now becoming standard procedures. As a result, much of the history of early work is to be rewritten. . . ."

Results of chemical analyses of 59 dated samples are given in Table XIX and those of 7 undated samples from miscellaneous sites in Table XX. About the dated samples there are considerable uncertainties and accordingly wide date range brackets have been given. Regarding Taxila, Caley points out that though the samples are believed to be earlier than the sixth century A.D. some may be as early as the fourth century B.C. Glass specimens have been found from the Bhir Mound, stratum IV ascribed to 6th–7th century B.C., several beads, bangles and other objects from stratum III

TABLE XIX

Percentage Chemical Compositions of Some Dated Ancient Indian Glass Specimens

Place	Taxila						
Date	600 B C.–300 B.C.						
Nature of glass specimen	Red opaque	White opaque	Haematinum strips	Green blue tile	Turquoise blue powder (decomposed)	Light green flask	Green blue tile
No.	1	2	3	4	5	6	7
Major constituents							
SiO_2	37.09	61.32	39.79	70.57	67.48	68.34	71.01
Na_2O	10.33	19 26	10 02	14.99	2 48	17.76	14.99
CaO	6.46	9.74	2 81	4 60	4.92	8.44	3.73
Minor constituents							
K_2O	0.87	1 00	0 57	2.65	0.55	0.94	2.65
MgO	0.70	1.64	?	2.68	1.80	1.44	2.32
Al_2O_3 }	3 16 }	1.70 }	2 45 }	2.46	3.64 }	1.67	3.74
Fe_2O_3 }				1.60		1.20	1.84
MnO	0.11	0.26	?	0.05	—	0.34	0.05
TiO_2	—	—	—	—	—	—	
Colouring agents							
CuO	—	—	—	0.55	3.63	—	0.24
Cu_2O	7.20	nil	—	—	—	—	—
Cu	—	—	5.31	—	—		
Other oxides							
PbO	34.85	nil	38.93				
SnO_2			0.22				
Sb_2O_3	nil	5 08	—	—	2.42		
BaO							
P_2O_5							
SO_3							
H_2O	—	—	—	—	14.15	0.43	
Total	100.77	100.00	100.10	100.15	101.07	100.56	100.57
$Na_2O.K_2O$	11.20	20.26	10.59	17.64	3.03	18.70	17.64
CaO.MgO	7.16	11.38	2.81	7.28	6.72	9 88	6.05
R_2O_3	3.16	1.70	2.45	4.06	3.64	2.87	5.58
N_2O/K_2O	11.9	19.26	17.6	5.6	4.5	18.9	5.6
CaO/MgO	9.2	6 00	—	1.7	2.7	5.9	1 6

1, 2. Sana Ullah, *ASI/AR* (1921–22), 125.

3–7. Sana Ullah, *ASI/AR* (1922–23), 158; regarding sample 3, Caley recalculated Cu value as Cu_2O value of 5.98, pp. 50–51.

TABLE XIX (*contd.*)

Percentage Chemical Compositions etc.

Place	Taxila				Rajghat		
Date	600 B.C.–300 B.C.				600 B.C.–200 B.C.		
Nature of glass specimen	Amethyst glass	Brown (fragments)	Light blue (curved fragments)	Blue bangle	Translucent black bead	Translucent blue green bead	Transparent olive green bead
No.	8	9	10	11	12	13	14
Major constituents							
SiO_2	58.12	53.81	70.69	68.11	64.68	70.09	67.07
Na_2O	16.74	23.52	12.86	19.10	17.54	5.29	13.81
CaO	8.85	6.27	7.05	4.91	5.42	8.90	6.35
Minor constituents							
K_2O	4.83	2.35	4.85	—	0.30	9.74	0.36
MgO	4 01	4.50	0.50	3.74	0.86	1.10	0.44
Al_2O_3	5.74	1.51	2.88	2.22	7.89	3.34	9.95
Fe_2O_3	1.74	8.47	0.81	2.27	4.20	1.26	2.58
MnO	0.17	0 08	0.01	—	—	—	—
TiO_2							
Colouring agents							
CuO	—	—	—	0.44	—	1.13	
Other oxides							
PbO		—					
SnO_2		—					
BaO							
P_2O_5							
SO_3							
S_2O							
Total	100.20	100.51	99.65	100.79	100.89	100.85	99.56
$Na_2O.K_2O$	21.57	25.87	17.71	19.10	17.84	15.03	14.17
$CaO.MgO$	12.86	10.77	7.55	8.65	6.28	10.00	6.79
R_2O_3	7.48	9.98	2.69	4.49	12.09	4.50	12.53
Na_2O/K_2O	3.5	10.00	2.6	α	58.5	0.54	38.1
CaO/MgO	2.2	1.4	14.1	1.3	6.3	8.1	14.4

8–11. Sana Ullah, *ASI/AR* (1922–23), 158. 12–14. Bharadwaj, 42–46.

TABLE XIX (*contd.*)
Percentage Chemical Compositions etc.

Place	Rajghat		Kopia				
Date	600 B.C.–200 B.C.		300 B.C.–300 A.D.				
Nature of glass specimen	Translucent pale blue bead	Opaque reddish brown bead	Black perforated bead	Pale greenish yellow bead	Blue black lozenge shaped	Opaque bead, blue with black & red decoration	Opaque black bangle
No.	15	16	17	18	19	20	21
Major constituents							
SiO_2	68.05	65.01	62.24	70.30	64.80	67.13	66.13
Na_2O	16.03	13.05*	16.70	19.31	21.03	19.61	21 70
CaO	8.04	4 08	3.13	2.38	3 71	3.03	2.24
Minor constituents							
K_2O	0.62	*	—	—	—	—	—
MgO	0.98	0.49	1.55	1.20	2.10	1.60	1.33
Al_2O_3	2.76	2.28	8.46	5.30	4.90	6.70	7 26
Fe_2O_3	1.84	9.67	7.20	1.20	2.95	1.50	0 86
MnO	—	—	0.02	0.079	0.057	0.032	0 074
TiO_2	—	—	0.51	tr.	0 45	0.40	0.41
Colouring agents							
CuO	2.40	—	nil	nil	tr.	nil	tr.
Cu_2O	—	5.27	—	—	—	—	—
Cu							
Other oxides							
PbO							
SnO_2							
Sb_2O_3			nil	nil	S. tr.	S. tr.	nil
Cr_2O_3							
BaO							
P_2O_5							
SO_3							
NiO	—	0.15					
H_2O							
Total	100.72	100.00	99.81	99.77	100.00	100.00	100.00
$Na_2O.K_2O$	16.65	13.05	16.70	19.31	21.03	19.61	21.70
CaO.MgO	9.02	4.57	4.68	3.58	5.81	4 63	3.57
R_2O_3	4.60	11.95	15.66	6.50	7.85	8.20	8.12
N_2O/K_2O	25.8	α	α	α	α	α	α
CaO/MgO	8.2	8.3	2.0	2.0	1.8	1.9	1.7

* Na_2O and K_2O not differentiated.
15–16. Bharadwaj, 42–46. 17–21. Roy and Varshney, 366–68.

TABLE XIX (*contd.*)
Percentage Chemical Compositions etc.

Place	Kopia			Kausambı		
Date	300 B.C.–300 A.D.			200 B.C.–200 A.D.		
Nature of glass specımen	Transparent clear bead unperforated	Pale yellowish green broken piece from refractory piece	Glass from spout of refractory vessel	Green bead	Blue bead, cylinder circular	Opaque terracotta red bead, cylinder circular
No.	22	23	24	25	26	27
Major constituents						
SiO_2	63.30	66.60	60.72	65.08	76.42	57.34
Na_2O	20.52	21.70	18.30	13.57	4.11	7.50
CaO	3.64	2.40	8.85	2 23	3.14	3.30
Minor constituents						
K_2O	—	—	—	2.92	10.12	6.89
MgO	1.85	tr.	1.12	1 69	0.55	2.18
Al_2O_3	7.09	6.98	10.80	4.02	2.38	4.70
Fe_2O_3	2.50	1.62	0 20	1.122	1.187	4.48
MnO	0.095	0.026	—	—	1.42	0.39
TiO_2	1.01	0.51	—	0.293	0.105	0.38
Colouring agents						
CuO	nil	nil	nil	1.803	0.284	—
Cu_2O	—	—	—	—	—	10.89
Cu	—	—	—	—	—	—
Other oxides						
PbO	—	—	—	—	—	—
SnO_2	—	—	—	1.84	—	
Sb_2O_3	—	—	—	—	—	—
Cr_2O_3	nil	nil	nil			
BaO	—	—	—	—	—	—
P_2O_5	—	—	—	5.16	0.10	1.95
SO_3	—	—	—	0.25	—	—
H_2O	—	—	—	—	—	—
Total	100.01	99.83	99.99	99.978	99.816	100.00
$Na_2O.K_2O$	20.52	21.70	18.30	16 49	14.23	14.39
CuO.MgO	5.49	2.40	9.97	3 92	3.69	5.48
R_2O_3	9.59	8.60	11.00	5.14	3.57	9.18
Na_2O/K_2O	α	α	α	4.6	0.4	1.1
CaO/MgO	1.9	α	7.9	1.3	5.7	1.5

22–24. Roy and Varshney, 366–68. 25–27. Tornati, 23.

TABLE XIX (*contd.*)
Percentage Chemical Compositions etc.

Place	Tripuri				
Date	200 B.C.–100 B.C.	100 B.C.–200 A.D.		200 A.D.–400 A.D.	
Nature of glass specimen	Transparent bluish lump	Blue spherical bead	Blue bead	Transparent green spherical bulb	Opaque blue annular bead
No.	28*	29*	30*	31*	32*
Major constituents					
Si	20.00	17.00	12.00	15.00	25.00
Na	40.00	40.00	50.00	50.00	10.00
Ca					
Minor constituents					
K	—	—	—	—	—
Mg	12.00		12.00	10.00	12.00
Al			5.00	5.00	7.00
Fe	5.00	5.00	10.00	8.00	10.00
Mn					
Ti				6.00	
Colouring agents					
Cu	6.00	3.00	10.00	6.00	12.00
Other oxides					
Pb	5.00	—	10.00	5.00	20.00
Sn					
Sb					
Cr					
Ba	—	—	3.00	5.00	5.00
P					
S					
$Na_2O.K_2O$	n.d.	n.d.	n.d.	n.d.	n.d.
$CaO.MgO$	n.d.	n.d.	n.d.	n.d.	n.d.
R_2O_3	n.d.	n.d.	n.d.	n.d.	n.d.
Na_2O/K_2O	n.d.	n.d.	n.d.	n.d.	n.d.
CaO/MgO	n.d.	n.d.	n.d.	n.d.	n.d.

* Percentages of metals are given.
28–32. Dikshit (9), 136–39.

TABLE XIX (*contd.*)
Percentage Chemical Compositions etc.

Place	Ter (Osmanabad)				
Date	100 B.C.–200 A.D. (Sātavāhana period)				
Nature of glass specimen	Transparent pale green bead	Dark leafy green bead	Blue glass lump	Blue bead cylinder circular	Deep blue bead, cylinder circular
No.	33	34	35	36	37
Major constituents					
SiO_2	59.82	72.90	76.26	76.89	74.03
Na_2O	18 20	3.17	0.12	0.75	0.80
CaO	4.71	2.39	1.99	1.76	1.23
Minor constituents					
K_2O	1.65	11.39	14.37	12.92	16.10
MgO	tr.	0.28	0.63	0.59	0.77
Al_2O_3	9.90	2.28	1.77	3 34	2.13
Fe_2O_3	1 45	0.86	2.07	1.83	2.20
MnO	—	—	0.77	0.79	1.50
TiO_2	0 33	0.04	0.16	0.17	0.15
Colouring agents					
CuO	0.62	1.37	—	—	—
Cu_2O					
CoO			0.01	0.027	0.04
Other oxides					
PbO	2.05	3.72	—	—	—
SnO_2	0.20	0.17	—	—	—
Sb_2O_3					
Cr_2O_3	—	n.d.	0.0053	tr.	n.d.
BaO			0.13	0.28	tr.
P_2O_5					
SO_3	0.40	n.d	0.54	0.20	0.26
H_2O	—	—	—	—	—
Total	99.33	98.57	98 8253	99.547	99.21
$Na_2O.K_2O$	19.85	14.56	14 49	13 67	16.90
CaO MgO	4.71	2.67	2.62	2.35	2.00
R_2O_3	11.35	3.14	3.84	5.17	4,33
Na_2O/K_2O	11.00	0.28	0.008	0.58	0.05
CaO/MgO	α	8.5	3.2	3.00	1.60

Analysed spectrographically and chemically by Tornati and 33–37 published by Dikshit (9), 159. The following additional elements have been detected spectrographically (34)—V, Ni, Mn, Zr; (35)—Ba, Mn, B, Ag.V; (36)—V, Ni, Sr, B; (37)—V, B, Ni; (38) Ba, V, Cu, Ni.Pb.

TABLE XIX (*contd.*)

Percentage Chemical Compositions etc

Place	Nasık					Ahicchatra	
Date	100 B C.–200 A D. (Sātavāhana period)					1st cent. A D.	
Nature of glass specimen	Thick bottle green	Glass worked (black)	Cırcular glass ear-reels	Disintegrated glass	Disintegrated glass	Blue glass fragment	Green glass fragment
No.	38	39	40	41	42	43	44
Major constituents							
SiO_2	65 28	55.55	80.17	85 58	87.55	61 49	59.56
Na_2O	7.88	6.26	—	—	—	15.32	14.19
CaO	11.88	5.59	2.72	1.66	1 44	6.60	6.54
Minor constituents							
K_2O	1.06	16.12	2.41*	3.03*	2.58*	2.67	2 41
MgO	1.48	2.93	2.12	0.41	0.53	4.61	4.34
Al_2O_3	5.75	9.89	4.35	3 61	3.17	0.66	0 05
Fe_2O_3	4.78	3.06	2.00	1.96	1.49	5.29	5.40
MnO	1.73	tr.	—	—	—	—	0.06
TiO_2	—	—	tr.	—	—	—	—
Colouring agents							
CuO	—	—	—	—	—	2.39	1.82
Cu_2O							
Cu							
Other oxides							
PbO	—	—	—	—	—	—	4.23
SnO_2	—	—	—	—	—	—	—
Sb_2O_3	—	—	—	—	—	—	—
Cr_2O_3	—	—	—	—	—	—	—
BaO	—	—	—	—	—	—	—
P_2O_5	—	—	—	—	—	1.94	1 36
SO_3	—	—	—	—	—	—	—
H_2O	0.18	0.56	6.23	3.75	3.24	—	—
Total	100.02	99.96	100.00	100.00	100.00	100.97	99.96
$Na_2O.K_2O$	8.94	22 38	2.41	3.03	2.58	17.99	16.60
CaO.MgO	13.36	8.52	4.84	2 07	1.97	11.21	10.88
R_2O_3	10.53	12.95	6.35	5.57	4.66	5.95	5.45
Na_2O/K_2O	7.4	0.38	0.0	0.0	0.0	5 70	5.9
CaO/MgO	8.0	1.9	1.3	4.0	2.7	1 44	1.5

* Alkalies obtained by difference and not differentiated.

38–42. Lal (Dr) (1), 52–58. 43, 44. Lal (Dr) (1), 25.

TABLE XIX (*contd.*)
Percentage Chemical Compositions etc.

Place	Arikamedu							
Date	1st cent. A.D.							
Nature of glass specimen	Dark blue almost opaque	Deep violet	Bluish violet	Red glass	Green glass bead	A lump of glass material; colour not stated		
No.	45	46	47	48	49	50	51	52
Major constituents								
SiO_2	73.6	73.62	72.49	64.81	75.90	64.64	66 45	66.69
Na_2O	2.1	1.30	0.20	11.35	4.27	17.00	13.50	14.30
CaO	3.9	1.96	2.94	4.81	1.84	4.00	5.00	4.60
Minor constituents								
K_2O	13.4	12.78	14.14	4.32	3.93	3.50	3.90	4.00
MgO	1.4	0.30	0.68	2.35	1.31	1.60	2.10	2.00
Al_2O_3	1.9	1.38	1.12	3.41	2.88	5.80	5.10	4.50
Fe_2O_3	1.1	3 84	6.50	1.205	2.584	1.20	1.50	1.30
(FeO)	2.0							
MnO	0.4	5.01	1.99	—	—	0 25	0.15	0.14
TiO_2	—	—	—	0.311	0.163	0.15	0.30	0.27
Colouring agents								
CuO	—	—	—	0.721	1.50	1.70	1.90	2.10
Cu_2O	—	—	—	1.333	—	—	—	
CO_3O_4	—	—	—	—	—	0.005	0 005	0.005
Other oxides								
PbO	—	0.07	0.07	—	—	0.05	—	0.01
SnO_2	—	—	—	0.39	0.63	—	—	
Sb_2O_3	—	—	—	—	—	—	—	
Cr_2O_3	—	—	—	—	—	—		
BaO	—	—	—	—	—	0.10	0.10	0.09
P_2O_5	—	—	—	5.00	4.81(P_2O_3)	—	—	—
SO_3	—	—	—	0.10	0.20	—	—	—
V_2O_5	—	—	—	—	—	0.01	tr.	tr.
H_2O	—	—	—	—	—	—	—	—
Total	99.8	100.26	100.13	100.110	100.017	100.05	100.005	98.005
$Na_2O.K_2O$	15.5	14.08	14.34	15.87	8.20	20.50	17.40	18.30
CaO.MgO	5.3	2.26	3.62	7.16	3.15	5.60	7.10	6.60
R_2O_3	5.0	5.22	7.62	4.62	5.46	7.00	6.60	5.80
Na_2O/K_2O	0.15	0.1	0 01	2.6	1.1	4.8	3.46	3.6
CaO/MgO	2 81	6.5	4.3	2.04	1.4	2.5	2.4	2.3

45. Subramanian, 19–20. 46, 47. Lal (Dr) (1), 25, 26.
48, 49. Tornati, 23. 50, 51, 52. Lamb, 87.

TABLE XIX (*contd.*)
Percentage Chemical Compositions etc.

Place	Nalanda						Kolhapur
Date	400 A.D.–900 A.D.						1300 A.D.–1500 A.D.
Nature of glass specimen	Light blue fragment	Sky blue fragment	Green glass rectangular object	Opaque red glass bead	Blue glass	Decayed glass	Transparent light blue bangle
No.	53	54	55	56	57	58	59
Major constituents							
SiO_2	62.61	61.21	70.74	61.50	63.44	56.72	45.45
Na_2O	17.85	18.25	15.80	15.92*	15.69	3.62	35.74
CaO	6.95	8 15	2.11	5.20	8.00	11.95	9.09
Minor constituents							
K_2O	5.04	4 98	2.94	—	1.54	0.49	—
MgO	4.17	3.83	0.26	0.06	4.14	3.17	3.37
Al_2O_3	2.05	1.81	6.13	9.82	6.90 }	2.77	2.40
Fe_2O_3	1.61	1.60 (FeO)	1.54 (FeO)	7.01		1.59	2.14
MnO	0 06	—	tr.	—	tr.	tr.	—
TiO_2	—	—	—	—	—	—	—
Colouring agents							
CuO	0.57	0.75	—	—	1.13	0.79	1.81
Cu_2O	—	—	—	0.49	—	—	—
Cu	—	—	—	—	—	—	—
Other oxides							
PbO	—	—	—	—	—	—	—
SnO_2	—	—	—	—	—	—	—
Sb_2O_3	—	—	—	—	—	—	—
Cr_2O_3	—	—	—	—	—	—	—
BaO	—	—	—	—	—	—	—
P_2O_5	—	—	—	—	—	—	—
SO_3	—	—	—	—	—	—	—
CO_2	—	—	—	—	—	12.80	—
H_2O	—	—	—	—	—	7.16	—
Total	100.91	100.58	99.52	100.00	100.84	101.06	100.00
$Na_2O.K_2O$	22.89	23.23	18.74	15.92	17.23	4.11	35.74
CaO.MgO	11.12	11.98	2.37	5.26	12.14	15.12	12.46
R_2O_3	3.66	3.41	7.67	16.83	6.90	4.36	4.54
Na_2O/K_2O	3.54	3.7	5.4	α	10.2	7.4	α
CaO/MgO	1.66	2.1	8.1	87.0	1.9	3.7	2.7

* Alkalies not differentiated.

53–56. Sana Ullah, *ASI/AR* (1922–23), 158: (1930–34), 300. Regarding sample 56, Caley put the value of K_2O as 4.98 instead of 2.94 as given in the original estimate; Sana Ullah's original summation is therefore correct.

57, 58. Lal (Dr) (1), 23. 59. Lal (Dr) (2), 51; alkalies not differentiated.

TABLE XX
Percentage Chemical Composition of Undated Glass Objects from Miscellaneous Sites

Place	Assam	Kurukshetra	Rairh (Jaipur)	Udayagiri (Gwalior)	Dargai (Malakand Agency, Pakistan)		Agra, Taj Mus. (late Mughal)
Nature of glass specimen	Flat coral red bead	Bluish green bangle, partly decomposed	Taurine shaped object	Black cylindrical weight	Blue glass	Colourless glass	Blue glass from flask
No	1	2	3	4	5	6	7
Major constituents							
SiO_2	53.25	85.34	76.15	59.62	60.48	62.14	60.15
Na_2O	11.69	1.20*	10 97*	4.10	19.94	20.09	20 67
CaO	9.18	2.74	4.58	7.55	8.67	8.71	3 27
Minor constituents							
K_2O	—	—	—	19.00	2 70	2 68	—
MgO	1.47	2.59	tr.	2.03	2.57	2 97	2.83
Al_2O_3	6.12	3.88	1 97	3 42	2.92	2.61	10.26
Fe_2O_3	8.24 (FeO)	1.72	6.33	3.21	2.60	1.26	1.49
MnO	—	—	—	—	tr.	tr.	—
TiO_2	—	—	—	—			
Colouring agents							
CuO	—	2.53	—	—	0.68	—	1.33
Cu_2O	10.28	—	—	—	—	—	
Cu	—	—	—	—	—	—	
Other oxides							
PbO							
SnO_2							
Sb_2O_3							
BaO							
P_2O_5							
SO_3							
H_2O							
Total	100.23	100.00	100.00	98.93	100.60	100 46	100.00
Na_2O K_2O	11.69	1.20	10 97	23.10	22.64	22.77	20.67
CaO.MgO	10.65	5.33	4.58	9.58	11.24	11.68	6.10
R_2O_3	14.36	5.60	8.30	6.63	5.52	3.87	11.75
Na_2O/K_2O	α	α	α	0.22	7.4	7.5	α
CaO/MgO	6 2	1.06	α	3.7	3.4	2 9	1.15

1, 2, 4. Sana Ullah, *ASI/AR* (1922–23), 158. Regarding 1, Caley reworked original Fe_2O_3 value as FeO 8.24 and that of 9.13 for metallic copper as Cu_2O 10.28, which represent the data more accurately, pp. 50–51. 3, 5, 6, 7. Sana Ullah, *ASI/AR* (1924–25), 139.

* By difference.

ascribed to 5th century B.C., from stratum II of the Mauryan period, from the Śaka-Parthian Stratum at Sirkap and so on, as described in chapter II. Regarding Kopia, Roy and Varshney have given the date of 5th century B.C., but archaeologists have preferred a later date, 3rd century B.C. to 3rd century A.D. The date of glass objects from Nalanda is debatable. From the coins of Kumāragupta I (414–455 A.D.), Narasimhagupta (*c.* 470–473 A.D.), Śaśāṅka (1st half of the 7th century A.D.) and Bhoja I (*c.* 840–890 A.D.), the glass objects examined may belong to any period between the 5th and the 9th century A.D. Regarding other specimens, dates given by the analysts are mentioned. Some of the undated samples are likely to belong to early dates given for samples in Table XIX, as their compositions appear to imply.

Dated samples bearing Nos. 5, 40, 41, 42 and 58 and undated sample No. 2 represent disintegrated or decomposed examples and will be discussed separately. Sample No. 24 is described as unmelted, but sintered glass batch. 8 samples contain appreciable amounts of lead up to 38.93 per cent of PbO and 20 per cent of Pb and 2 samples traces of PbO. Barium, tin, cobalt and various trace elements have been detected where spectrographic methods have been applied. All the systems, excluding a few high lead containing ones, are soda-lime glasses showing wide variations in composition to be expected from their geographical distributions and differences in their dates of manufacture.

We shall first consider the compositional patterns of silica, alkalis, lime and magnesia and aluminium oxide shown under major and minor constituents. The oxides of iron, manganese, copper, lead, barium, cobalt, tin, etc. will be discussed under colouring agents. At the bottom of each table, the summation of total alkalies, alkaline earths (CaO.MgO), R_2O_3 and the ratios of Na_2O/K_2O and CaO/MgO have been given for each sample. Caley has given the ratios of K_2O/Na_2O and MgO/CaO. He has also given the ratios of Al_2O_3/SiO_2; although we have not indicated them in our tables, the average of such ratios has been calculated for purposes of comparison with similar ratios for Egyptian, Assyrian and Roman glass.

Silica. The average percentage of 8 Taxila samples (excluding Nos. 1, 3 and 5) is 65.25%; of 5 Rajghat samples 66.98%, of 7 Kopia samples (excluding No. 24) 65.15%; of 3 Kausambi samples 71.98%; of 2 Nasik samples (excluding Nos. 40, 41 and 42) 60.41%; of 2 Ahicchatra samples 55.52%; of 8 Arikamedu samples 69.78% or 68.90% excluding sample No. 49 which may have decomposed as suspected from low alkali content, and 5 Nalanda samples (excluding No. 58) 63.90% (Table XXI). Neither the averages nor the individual values show noticeable consistency. Higher percentages of SiO_2 have been used in glasses later than Taxila's, but Nasik, Ahicchatra and Nalanda register lower values. Taxila's historical background calls for a comparison with data of glass samples from the Near East as does Arikamedu's with the Roman ones. As discussed in chapter I, the average of 7 Mesopotamian samples as per our tables is found to be 65.76%; Turner's average is 65.84%; Caley's average of 12 samples is 65.50%. These average values are closely in agreement with the value of 65.25% for Taxila glasses. Regarding Roman glasses, we have given our average of 68.07%, based on 13 samples. Caley has given an over-all average of 68.56%; but for 1st century A.D. Weisenau glass specimens from Roman Germany, his average

TABLE XXI

Variation in Proportion and Average Proportions of Major Components

Place		SiO_2	$Na_2O.K_2O$	$CaO.MgO$	Al_2O_3	Al_2O_3/SiO_2
Taxila		71.01	17.64	6.05	3.74	
		70.69	17.71	7.55	2.88	
		70 57	17.64	7.28	2.46	
		68.34	18.70	9.88	1.67	
		68.11	19 10	8.65	2.22	
		61 32	20.26	11.38	—	
		58 12	21 57	12.86	5.74	
		53.81	25 87	10.77	1.51	
	Av. =	65.25	19 81	9.30	2.89	0.044
Rajghat		70 09	15.03	10.00	3.34	
		68.05	16 65	9.02	2.76	
		67.07	14.17	6.79	9.95*	
		65.01	13.05	4.57	2.28	
		64 68	17.84	6.28	7.89*	
	Av. =	66.98	15.35	7.33	5.24	0.078 0.041 * excluding two samples
Kopia		70.30	19.31	3.58	5.30	
		67.13	19.61	4.63	6.70	
		66.60	21.70	2.40	6.98	
		66.13	21.70	3.57	7.26	
		64.80	21 03	5.81	4.90	
		63.30	20.52	5.49	7.09	
		62 24	16.70	4.68	8.46	
	Av. =	65.79	20 08	4.31	6.67	0.102
Kausambı		76.42	14.23	3.69	2.38	
		65.08	16.49	3.92	4.02	
		57.34	14.39	5.48	4.70	
	Av. =	66.28	15.04	4.36	3.70	0.056
Ter		76.89	13.67	2.35	3.34	
		76.26	14.49	2 62	1.77	
		74.03	16.90	2.00	2.13	
		72.90	14 56	2.67	2.28	
		59.82	19.85	4.71	9.90*	
	Av. =	71.98	15.89	2 87	3.88	0.054 0.033 * excluding sample

(contd.)

TABLE XXI (*contd.*)
Variation in Proportion and Average Proportions of Major Components

Place		SiO_2	$Na_2O.K_2O$	CaO MgO	Al_2O_3	Al_2O_3/SiO_2
Nasik		65.28	8.94	13.36	5.75	
		55.55	22.38	8.52	9.89	
	Av. =	60.41	15.66	10.94	7.82	0.13
Ahicchatra		61.49	17 99	11 21	0.66	
		59.56	16.60	10.88	0.05	
	Av. =	55 52	17.29	11.04	0.36	0.0065
Arikamedu		75.90*	—	—	2.88	
		73.62	14.08	2.26	1.38	
		73.60	15.50	5.30	1.90	
		72.49	14.34	3.62	1.12	
		66.69	18.30	6.60	4.50	
		66.45	17.40	7.10	5.10	
		64.81	15.87	7.16	3.41	
		64.64	20.50	5.60	5.80	
	Av. =	69.78			3.26	0.047
* excluding	Av. =	68.90	16.57	5.38		
Nalanda		70.74	18.74	2.37	6.13	
		63.44	17.23	12.14	—	
		62.61	22.89	11.12	2.05	
		61.50	15.92	5.26	9.82*	
		61.21	23.23	11.98	1.81	
	Av. =	63.90	19.60	8.57	4.95	0.077 0.052 * excluding sample

is 69.61 %. These values are comparable with the average value of 69.78 % (or 68.90 %) for Arikamedu specimens. In general, Indian specimens are characterized by higher SiO_2 percentages, which may be due to the use of good quality sand, sandstone or quartz, widely distributed throughout India, as analyses given in Table XXV appear to indicate.

Alkalies. Na_2O has been found in all the 66 samples, dated and undated, with the exception of Nos. 40, 41 and 42 for which Na_2O and K_2O were not separately determined. K_2O has been found in 42 samples, varying from 0.30 % in a Rajghat sample to 19.0 % in a specimen from Udayagiri. Two samples from Taxila contain little less than 5.0 %; 1 from Rajghat 9.74 %; two from Kausambi, 10.12 % and 6.89 %; 4 from Ter between 11.39 to 16.10; 1 from Nasik 16.12 %; 3 from Arikamedu between 13.4

to 14.14%; 2 from Nalanda about 5.0%, all of which may be considered as potash-rich specimens. In others K_2O was added to improve the quality of glass. In 17 samples, K_2O has not been found and in 7 samples the two alkalies have not been differentiated. Egyptian glass from the 18th to 17 dynasties to 1st century A.D. contain small amounts of K_2O, with average values lying at 2.17%, 2.29%, 1.97%, 0.62%, 0.55% and 0.17%. For Tell-el Amarna, the average is 3.18% and for Elephantine red opaque glass 5.60%.[a] Mesopotamian glass again shows the use of small amounts of K_2O, averaging 2.11, with the highest value at 3.18% (Caley's table). Roman glasses from Germany (1st to 5th century A.D.) contain still smaller amounts of K_2O—average values being 1.21%, 1.06%, 1.29%, 0.80% and 1.75%. Potash-rich glass specimens are known from medieval Central Asia and Western Europe (see Tables VI and VII).

The picture is more consistent when we consider the total alkalies (Table XXI). The average range lies between 15.04% to 20.08%, but there is no time sequence. Such variations in total average alkalies for different periods are to some extent comparable with those of Egyptian samples, ranging from 15.25% to 21.55%.[b] Mesopotamian glasses used lower amounts of alkalies—14.50% to 17.71%.[b] The most consistent use of alkalies is recorded in the Roman Rhine-province specimens, the average being 18.18% (Caley) and 19.76% (Bezborodov) (Table II). For some specimens from Cologne and Mainz, Caley has given little higher averages, e.g. 19.79% and 21.20%.[a] The average and individual values for Arikamedu specimens clearly show that lesser amounts of them were used than in the Roman.

As in Egypt, India also has a few soda lakes as source of sodium carbonates and other salts. The soda-bearing *reh* soils widely distributed in India also constituted an important source of sodium salts, as we shall see in what follows. Potash, as elsewhere, was derived mainly from plant ashes; it could also come from the soda lakes like the Lonar, containing appreciable amounts of potash.

Calcium and magnesium oxides. The total lime and magnesia content shows wide variations. Taxila, Nasik, Ahicchatra and Nalanda show high averages between 8.57 to 11.04%. The lowest average of 2.87% is recorded in Ter samples. Such wide variations are also noticed in Egyptian and Mesopotamian glasses (see Table I). Caley's averages are: 18th–17th dynasty—12.30%; Tell-el Amarna (14th century B.C.)—13.32%; Alexandria (1st century B.C.–1st century A.D.)—11.08%; Elephantine (2nd–1st century B.C.)—9.49%. Some averages for Mesopotamian specimens are: 10.93%; 8th–6th century B.C.—10.79%; 3rd century B.C.—11.34%. These averages are all higher than those found in Indian specimens. The Roman samples (Table II) show considerable consistency, their average being 8.01% (Bezborodov) and 7.43% (Caley). Thus noticeably lower amounts of lime and magnesia were used in Roman glass. It should be noted that Arikamedu specimens showed up still less, their average being 5.38%. From the point of view of magnesium content, the Indian specimens are generally characterized by low magnesia concentration, although high magnesia samples have also been encountered. The exceptions are two samples from Taxila (4.01 and 4.50%), two samples from Ahicchatra (4.61 and 4.34%), 3 samples from Nalanda (4.17, 3.83 and 4.14%) and 1 sample from Kolhapur (3.37%) (see Table XIX).

[a] Caley, 68ff. [b] Caley, 68, 72, 84–85, 98, 101.

Naturally occurring limestones contain a major proportion of CaO and small amounts of MgO. Dolomites and dolomitic limestones contain higher proportions of MgO. For Indian dolomite samples, the ratio of CaO/MgO, as we have shown in Table XXX, lies between 1.4 to 1.9. A perusal of Table XIX shows that glass samples numbered 4, 7 and 9 from Taxila, 17 to 23 from Kopia, 27 from Kausambi, 37 from Ter, 39 from Nasik, 43 and 44 from Ahicchatra, 48 and 49 (decomposed) from Arikamedu and 54 and 57 from Nalanda show CaO/MgO ratios falling between 1.4 to 1.9. In a few cases, this ratio is around 2.0, and these have been included. For Kopia specimens (the ratio lying between 1.7 to 2.0%), Caley has observed that such a high proportion of magnesia 'obviously indicates the use of dolomite or dolomitic limestone as a raw material'.[a] If this be so, the use of dolomite or dolomitic limestone appears to be indicated in the above-mentioned samples and is further corroborated by the widespread natural distribution in India of these double carbonates of calcium and magnesium.

Alumina. This almost universal component of all ancient glass specimens obviously passed into the glass batch from clay and other minerals present in sand. The clay pots used for melting purposes also introduced this oxide. The percentage-range from very small amounts to about 5% can be explained in this way. Our tables show percentages of alumina much higher than this limit in a number of cases, of which typical examples are those from Kopia (5.30 to 8.46%), Rajghat (7.89% and 9.95%), Ter (9.9%), Nasik (5.75%, 9.89%), Nalanda (6.13%–9.82%), blue glass flask from Taj (10.26%). Intentional use of felspar has been suggested in such cases. If we exclude Nasik and Kopia (Table XXI), the average Al_2O_3/SiO_2 ratios for Indian samples compare favourably with similar averages from Egyptian, Mesopotamian and Roman specimens, as the following data from Caley will show:

		Al_2O_3/SiO_2
Egypt	Thebes (15th century B.C.)	0.045
	Tell-el-Amarna (14th century B.C.)	0.024
	Elephantine (2nd–1st century B.C.)	0.039
	Alexandria (1st century B.C.–1st century A.D.)	0.065
Mesopotamia	3rd century B.C.	0.033
Roman Germany	1st century A.D.	0.054
	2nd century A.D.	0.048
	3rd–4th century A.D.	0.043

Colouring Agents and Other Oxides

Based on analyses of glass samples from Kopia, Taxila, Nalanda and a few miscellaneous samples analysed by Sana Ullah, Caley in 1962 could classify two

[a] Caley, 87; as already pointed out, he calculated MgO/CaO ratios for all samples; for Kopia, his values are: 0.57, 0.51, 0.50, 0.53, 0.50, 0.59; av. = 0.46 and 0 53, if one analytical value is excluded from the average.

TABLE XXII
Glasses Coloured with Iron and Manganese

No given in Table	Fe_2O_3 %	FeO %	MnO %	Colour
XIX 6	1.20		0.34	Light green
8	1.74		0.17	Amethyst
9	8.47		0 08	Brown
10	0.81		0.01	Light blue
17	7.20		0.02	Black
18	1.20		0.079	Pale greenish yellow
19	2.95		0.057	Blue black
20	1.50		0.032	Opaque, with blue and red decoration
21	0.86		0.074	Opaque black
23	1.62		0.026	Pale yellowish green
38	4.78		1.73	Bottle green
39	3.06		trace	Black
45	1.10	2.00	0.4	Dark blue
46	3.84		5.01	Deep violet
47	6.50		1.99	Bluish violet
55		1.54	trace	Green glass

groups of Indian glasses, one coloured by oxides of iron and manganese and the other group by iron, copper and manganese. As no cobalt was reported in the analyses available to him, he stated, "Cobalt and other less usual colouring components have not been found in ancient Indian glasses."[a] He also reported one lead glass specimen. The analyses presented in our tables indicate that the situation has considerably changed during the last 12 years or so. Cobalt has been detected in quite a few samples; lead is now known in 10 samples; strontium, barium, tin and several other elements have been found in ancient Indian glasses. The specimens of which analyses have been given in our tables are mostly coloured glasses and a few opaque ones. Analyses of nearly colourless and clear Indian glass specimens have rarely come to our notice except No. 22 (Kopia), Sayre's analyses of Brahmanabad specimens (Table XII) already discussed, and an undated specimen from Dargai (Table XX).

Glasses coloured with Iron and Manganese. Varying percentages of Fe_2O_3 and MnO in glasses coloured with iron and manganese oxides only are shown in Table XXII. Compared to Egyptian and Roman glasses coloured with Fe_2O_3 and MnO

[a] Caley, 88.

only, the Indian samples in general show higher percentages of Fe_2O_3 and lower ones for MnO. A dark blue Egyptian glass contains 0.89% of Fe_2O_3 and 0.75% of MnO; for a light green Roman specimen, these percentages are 0.39 and 0.38 respectively.

Glasses coloured with Iron, Copper and Manganese. In Table XXIII, percentages of colouring agents in glasses coloured with iron, manganese and copper oxides are presented. Colours in these specimens were developed in the majority of cases by the combined action of iron and copper oxides. Manganese was present in 6 cases and in traces in two samples. The five red samples all contain Cu_2O and two of them FeO. In Egyptian, Mesopotamian and Roman glasses coloured with oxides of these three elements, all the three colouring agents are generally present. Whether a more accurate method of analysis will reveal the presence of manganese in these samples can only be decided by further analytical investigations.

Cobalt in Blue Glasses. Intentional addition of cobalt in small amounts varying from a fraction to one-thousandth part of 1%, although rare, has been established for a few ancient glass specimens from Egypt, Mesopotamia, Roman Rhineland, Korfun, Japan, and pre-Han China. Components of glasses coloured with cobalt, along with Fe_2O_3, MnO and CuO are shown in Table XXIV for Indian as well as for a few foreign specimens.

Lead, Antimony, Barium, Tin and other oxides. Lead has been found in 10 Indian specimens given in Table XIX—in Taxila, Tripuri, Ter and Arikamedu. In Nos. 1 and 2 from Taxila, the percentages of PbO are 34.85% and 38.93%; together with Cu_2O and Cu, such high amounts of lead were responsible for producing the sealing-wax red colour of which examples are known from Nimrud, Assyria (8th century B.C.), Elephantine (200–100 B.C.), Chinese beads (220–206 B.C.), Tara Hill, Ireland.[a] For Tripuri samples, percentages of metals have been given, lead showing up from 3% to 12.00%. The samples are bluish to opaque blue; the colours are likely to be due to ferric oxide and cupric oxide. In Ter, 2.05% PbO is associated with a pale green bead and 3.72% with a dark leafy green bead. Specimens 46 and 47 each contain 0.07 PbO in deep violet and bluish violet glasses found in Arikamedu.

Presence of antimony in a white opaque specimen (No. 2) and turquoise blue powder (No. 5), both from Taxila, was at one time considered significant and Lal commented that the addition of antimony in appreciable amounts in special glasses was a recent development.[b] As we have discussed in chapter I, the use of antimony as a decolorizer and also as an opacifier was an established practice in the ancient Near East. In variously coloured glasses, Sb_2O_5 found its use in percentages varying from 0.1 to 3.2, as Sayre showed. Turner and Rooksby found 8.8% of Sb_2O_5 in Roman opal glasses of 1st century A.D. and 2.8% to 4.5% in opaque coloured glasses from Nimrud (8th to 6th century B.C.)

Barium has been detected in specimens from Tripuri (30, 31, 32), Ter (35, 36) and Arikamedu (50, 51, 52). Dikshit stated that barium is reported from Tripuri only in a few cases,[c] e.g. Taxila (3), Kausambi (25), Ter (33, 34), Arikamedu (48, 49); in other words, in samples subjected to modern methods of analyses, including the optical and x-ray spectrographic and electron-probe methods. This is substantiated

[a] Turner (4), 174T. [b] Lal (Dr) (1), 21. [c] Dikshit (9), 160.

TABLE XXIII

Glasses Coloured with Iron, Manganese and Copper

No. given in Table	Fe_2O_3 %	FeO %	MnO %	CuO %	Cu_2O %	Colour
XIX 4	1.60		0.05	0.55		Green blue
5	3.64 (with Al_2O_3)			3.63		Turquoise blue (decomposed)
7	1.84		0.05	0.24		Green blue
11	2.27		none	0 44		Blue
13	1.26		none	1.13		Blue green
15	1.84		none	2.40		Pale blue
16	9.67		none	—	5.27	Opaque reddish brown
25	1.122		none	1.803		Green
26	1.187		1 42	0.284		Blue
27	4.48		0.39	—	10 89	Opaque terracotta red
33	1.45		none	0 62		Pale green
34	0.86		none	1.37		Dark leafy green
43	5.29		none	2.39		Blue
44	5.40		0.06	1.82		Green
48	1.205		none	0.721	1.333	Red
49	2.584		none	1.50		Green
53	1.61		0.06	0.57		Light blue
54	1.60		none	0.75		Sky blue
56	—	7.01	none	—	0 49	Opaque red
57	6 90 (with Al_2O_3)		trace	1.13		Blue
59	2.14		none	1.81		Light blue
XX 1	—	8.24	none	—	10.28	Coral red
5	2.60		trace	0.68		Blue
7	1.49		none	1.33		Blue

TABLE XXIV

Glasses Coloured with Cobalt and Other Colouring Components

Country	Table	No.	Fe_2O_3 %	MnO %	CuO %	CoO %	Co_3O_5 %	Colour
India	XIX	35	2.07	0.77	none	0.01		Blue
		36	1.83	0.79	none	0.027		Blue
		37	2.20	1.50	none	0 04		Deep blue
		50	1.20	0 25	1.70	—	0.005	Unstated but appears to be blue
		51	1.50	0.15	1.90	—	0.005	,,
		52	1.30	0 14	2.10	—	0.005	,,
Egypt	I	4	1 71	0.163	0 005	0 55	—	Blue
		5	0.50	0.38	0.01	0 075	—	Blue
		6	0.85	0.17	0.13	0.29	—	Blue
Mesopotamia	I	12	0.97	0 65	1.94	0.93	—	lapis lazuli
Roman	Caley, Table CXXVII		0.51	0.15	0.15	0.08		Bright blue
	,, ,,		0 61	0 25	0.12	0.13		Bluish green
Japanese	Caley, Table XLVII		1.30	0 50	none	0.47		Dark blue
Arabian	I	58	3.01	0 294	0.68	0.155		Deep blue
Samara	I	59	0 69	2 17	0.06	0.002		Blue
Western Europe, Reims	I	70	0.79	3.00	0.13	0.25		Blue

by the detection of a large number of elements present in traces, e.g. vanadium, nickel, zirconium, boron, silver, strontium, chromium, besides the others already discussed, in Indian samples from Ter, analysed by Dr. Tornati.

DECOMPOSED GLASS

We have already noted the results of chemical analyses of 6 samples of decomposed glass, e.g. No. 5 from Taxila, Nos. 40, 41 and 42 from Nasik, No. 58 from Nalanda, all in Table XIX and No. 2 of Table XX from Kurukshetra. All of these decomposed samples contain low alkalies, e.g. 3.03%, 2.41%, 3.03%, 2.58%, 4.11% and 1.2%, and appreciable amounts of H_2O, e.g. 14.15%, 6.23%, 3.75%, 3.24%, 7.16% and none. Silica registers very high percentages; although it is not marked in Nos. 5 and 58, other decomposed samples give SiO_2 as follows: 40–80.17%; 41–85.58%, 42–87.55%, and 2 (Table XX)—85.34%. Other oxides do not show strikingly different percentage compositions. Unless the sample is completely decomposed

from the surface to the core, partially decomposed samples usually contain a core of unaltered glass superimposed by decomposed layers. Accordingly, it is necessary to have complete analyses of both the decomposed outer layers and the unaltered glass at the core in order to have an understanding of the effect of subsoil and ground water conditions in India on ancient glass. So far there are few studies of decomposed glasses. The earliest qualitative examination is due to R. Bandes in 1824 and the earliest quantitative estimation is credited to J. G. A. Geuther.[a] Geuther analysed both the unaltered and the decomposed portions and found that the alkalies, Na_2O—21.7% and K_2O—3.0%, of the unaltered glass, disappeared completely from the decomposed fractions. There was not much change in SiO_2, but FeO and CaO percentages showed a marked increase through decompositions. Neumann's analysis of a partially decomposed Babylonian glass showed the decrease of Na_2O by 16%, K_2O by 43%, Fe_2O_3 by 9%, Mn_2O_3 by 65%, CaO by 33%, CuO by 44% and CoO by 70%. On the other hand, SiO_2 increased by 9%, Al_2O_3 by 18% and MgO by 12%. Turner's analysis of an Assyrian glass specimen shows loss of Na_2O from 12.70% to 1.38%, of K_2O from 0.88% to trace, CaO from 4.82% to 0.75%, to mention the same oxides; SiO_2 increased from 71.54% to 84.00%, Al_2O_3 from 0.48% to 1.66%, Fe_2O_3 from 0.91% to 1.27%.

The general consensus is that the decomposition of ancient glass is primarily brought about by the ground water. Ancient glass objects found in dry locations, as in Egyptian tombs, have suffered little or no decomposition. In prolonged contact with the ground water, glass objects undergo hydrolysis, soluble oxides such as the alkalies, oxides of manganese, calcium, magnesium, copper, etc. dissolve away at different rates depending on their solubilities, whereas the less soluble silica persists and gradually becomes hydrated. The increase in the percentages of FeO and CaO in Geuther's analysis has been explained by the addition of mineral matter from the ground water itself. Caley has summarized the present knowledge about decomposed glass as follows: "As far as the available data show, this residue is never pure silica, as has sometimes been stated. In fact, the residue often contains higher proportions of certain minor components, such as iron, than were present in the original glass. Usually not all of this can be accounted for on the basis of preferential rates of solution of the products of hydrolysis. This extraneous material must come from the surrounding soil or from mineralized ground water, and may be deposited by an exchange process or by adsorption on the hydrated silica".[b]

RAW MATERIALS FOR THE GLASS-MAKING INDUSTRY

For the soda-lime-silica glass, the principal raw materials are obviously silica, alkalies, limestones or dolomites, felspar and a few colouring agents like manganese, antimony, copper and tin compounds. Since a few examples of lead and barium containing glass exist, compounds of these metals should also be examined. We have little information about mining and quarrying for raw materials for various industries, including glass-making, in ancient India. Nevertheless, the knowledge we now possess

[a] Caley, 106–107. [b] Caley, 112–13.

about the natural occurrences and distribution of glass-making materials and their compositions will be helpful in an understanding of the glass samples found in archaeological sites.

SILICA

Thanks to the efforts of the Indian Tariff Board, the Geological Survey of India and the Council of Scientific and Industrial Research, we have now an extensive knowledge of the position of India with regard to glass-making sands. Sands in the form of sandstones, quartz and quartzites are extensively distributed throughout India, although there are pockets yielding material of an exceptionally high quality. Special mention should be made of the glass-making sand resources of Uttar Pradesh, Bihar, Panjab, Rajputana and Kashmir, Madhya Pradesh, as also Gujarat, Maharastra and the southern states of Tamil Nadu, Karnataka and Kerala.[a] The existence of some good quality sand has recently been reported from Sylhet in Bangladesh.

Uttar Pradesh. The well-known and the most extensive deposits have been found in the outskirts of the Vindhya mountain ranges south of Allahabad. There is a continuous chain of good sandstones between Jasra and Bargarh, covering places like Panhai, Lohagra and Dabhaura. The Bargarh deposits are estimated to cover an area of several hundred miles and have been worked for decades. Sands from this area are fine-grained, white and angular in shape. Panhai samples are a mixture of coarse and fine-grained sands, almost whitish, while Lohagra sands are fine-grained and slightly creamish in colour. Their chemical compositions are given in Table XXV.

Bihar. The southern districts of Bihar, e.g. Gaya, Santhal Parganas, Hazaribagh and Manbhum, contain rich deposits of sandstones, quartz and quartzites. Sandstones occur in Mangalhat near Rajmahal, Santhal Parganas, Tisra near Jharia, Johi Pafiari near Dhanbad and Beliad near Kumardhubi. Mangalhat sandstone is friable and contains 12% kaolin; it has also alluvial deposits of sand mixed with china clay, but with high silica content, good for glass making. Beliad sandstones are fine-grained and compact, with uniform grain-grade; Tisra sandstones are a superficial deposit of white colour and fine grade structure. Large deposits of quartz are known in Jhajha in Monghyr, Alakdiha in Gaya and Mazli in Hazaribagh. Jhajha quartz is of a good white colour, Mazli quartz occurs in pegmatite veins, and Alakdiha quartz is obtained from an outcrop rising above the alluvium. Large quartzite deposits occur as linear hill masses at a number of places in the northern Gaya and Monghyr districts. The chemical analyses are given in Table XXV.

Rajasthan, Panjab and Kashmir. In Rajasthan extensive deposits of fine-grained sand of dull white colour occur in Sawai Madhopur, which shows remarkable improvement upon sieving and washing. Good quality standstones are found in Jaijon-Doaba and Gurgaon in the Panjab (Table XXV), but the sandstones from Ghaggar near Ambala are of poor quality. In Kashmir, there is an extensive deposit of poor quality sand in Ban Talav.

Madhya Pradesh. Reasonably good glass-making sands occur in Jubbulpore in

[a] This section is mainly based on the survey of Indian resources of sands and rocks required for the glass industry by Atma Ram, Karimullah, Saboor and Verman.

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TABLE XXV

Chemical Composition of Sand, Sandstones, Quartz and Quartzites from Different Areas of India and Bangladesh.

(percentages given are of dried samples)

State & locality	Type	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Alkali	Loss on ignition	Total
Uttar Pradesh										
Bargarh	Sand	97.10	0.03	1.09	0.12	tr.	0.16	0.80	0.62	99.92
Panhai	,,	97.92	0.03	0.83	0.02	0 16	0.18	0.50	0.40	100.04
Lohagra	,,	98.86	0.05	0.61	0.01	0.10	tr.	0 05	0.37	100.05
Bihar										
Mangalhat	,,	99.08	0.05	0.33	0.08	tr.	nil	tr.	0.54	100.08
Beliad	Sandstone	98.16	0.16	0.75	0.06	tr.	0.17	tr.	0 37	99.67
Jhajha	Quartz	98.02	0.02	0.60	nil	0 48	0.28	tr.	0.26	99.66
Alakdiha	,,	97.41	0.03	1.87	nil	nil	0.16	tr.	0.16	99.63
Rajgarh	Quartzite	97.10	0.17	1.55	0.09	0.26	0.19	tr.	0.26	99.62
Rajasthan										
Sawai Madhopur	Sand	96.36	0.07	1.98	1.16	0.25	0.29	0.24	0.60	99.95
Panjab										
Jaijon-Doaba	Sandstone	98.42	0.05	0.95	tr.	0.18	0.05	tr.	0.36	100.01
Gurgaon	..	97.63	0.42	1.55	0.24	tr.	tr.	tr.	0.32	100.16
Kashmir										
Ban Talav	Sand	75.40	3.35	12.35	0.58	1.14	0.76	3.44	2.87	99.86
Madhya Pradesh										
Jabbulpore	Sand	96.60	0.04	1 57	0.28	0.20	0.47	nil	0.63	99.79
Gwalior, Banmore hill	Sandstone	94.19	0.26	4.19	0.17	0.31	tr.	0.07	0.66	99.85
Gwalior	Quartz	96.92	0.46	0.81	tr.	0.86	0.46	tr.	0.28	99.79
Maharashtra										
Walawal hills	Sandstone	98.52	0.05	0 71	0.04	0.20	tr.	0.10	0.12	99.74
Dhakka	,,	96.02	0.08	2.63	0.08	0.30	0.02	0.30	1.10	100.53
Gujarat										
Sangir	,,	97.50	0.09	1.62	0.11	tr.	0.37	nil	0.28	99.97
Karnataka & Andhra (Deccan Trap)										
Pasnapalli	Quartz	99.13	0.05	0.46	nil	nil	0.23	tr.	0.24	100.11
Kasmapalli	,,	99.55	0.05	0.16	tr.	nil	nil	tr.	0.16	99 92
Triq hill	,,	98.90	0.22	0.61	nil	tr.	0.31	tr.	0.30	100.34
Surapur	Quartzite	99.46	0.17	0.31	nil	nil	nil	tr.	0.12	100.06
Kodakal	Sandstone	94.22	0.14	3.20	nil	nil	0.11	2.06	0.69	100.42
Shettihalli (Karnataka)	Quartz	99.03	0.07	0.32	nil	nil	nil	nil	0.98	100.40

TABLE XXV (*contd.*)

State & locality	Type	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Alkali	Loss on ignition	Total
Andhra Pradesh										
Sankara mine	Quartz	99.16	0.07	0.22	nil	0.13	tr.	tr.	0.16	99.74
Palamani	,,	99.29	0.01	0 19	nil	0.14	nil	tr.	0.22	99.85
Eranavar	Sand	96.29	0.15	1.89	0 16	0.02	0.17	0.14	0.27	99.69
Kerala										
Pallanakkad	,,	97.65	0.04	1.00	0.36	0.15	0.32	tr.	0.41	99.93
Bangladesh										
Cochbari	,,	96.27	0.52	1.13	0.18	0.30	0.12	—	0.87	99.39
Shilghat	,,	97.01	0.30	1.27	0.13	0.37	0.13	—	0.54	99.75
Mirzapur 2	,,	97.75	0.14	0.66	0.30	0.23	tr.	—	0 59	99.67
,, (after sieving)	,,	98.64	0.10	0 36	0.15	0.14	tr.	—	0 39	99.78

a form of superficial bed and also as sub-soil layers varying in thickness from 3 to 10 inches. Extensive deposits of sandstones and quartz are found in Gwalior, but these are reported to be of poor quality, except the sandstones of Banmore hill, because of their high iron and alumina content (Table XXV). But this cannot be said of all areas as shown by the samples we have selected for our Table XXV, and there are several others which are compositionally suitable for glass-making.

Maharashtra and Gujarat (*formerly Bombay Presidency*, *Baroda state*). These states have also good resources of glass-making sands as comparatively recent surveys have indicated. When the Paisa Fund Glass Works were set up at Talegaon near Poona in 1908, the sand supplies came from Bargarh in U.P. and Sawai Madhopur in Rajasthan. In Maharashtra, in Walawal hills, 4 miles south of Malvan on the Ratnagiri coast, white and hard sandstones with fine grade, containing easily separable ferruginous layers, have been found. Ten miles from Malvan are located Dhakka hills with their sandstone deposits of light grey or creamy white materials with yellow, brown or red outer layers. In Gujarat, sandstones are available in very large quantities in Songir, Pedhamli and Lachharas, all situated in the former Baroda state, of which Songir sandstones are of the best quality.

Karnataka and Andhra (*parts formerly belonging to Hyderabad and Madras states*). Several parts of Hyderabad, Deccan, now falling within Maharashtra and Andhra, have good deposits of quartz, quartzite and sandstone. Quartz reefs occur in many places, in almost unlimited quantities. Some of these reefs are north-west of Pasnapalli and south of Kasmapalli, both near Narayanpet P.O.; west of Appadipalli-Maddur tract; north-west of Elredipalli near Kolakunda; reef forming Tariq hill near Mahboobnagar and other places. Good quartzite is available between Surapur and Humnabad and sandstone in the Kadakal plateau. All these quartz, quartzite and sandstone bearing areas lie within latitudes 16°19′45″ to 16°50′10″ and longitudes 76°20′25″ and 77°53′50″ in the bordering areas between Karnataka and Andhra

Pradesh. In Karnataka (former Mysore state) quartz and sand dunes are found over a considerable length at Shettihalli and Talakad on the banks of the Kaveri. In Andhra Pradesh, quartz of excellent quality occurs in Sankara mines, Gadala Tippa, Palamani and Talapur, all in Nellore district, in Eranavar near Ennore and in Chirala in Guntur district.

Kerala: Kerala contains extensive deposits of sands, but the material is usually contaminated with ilmenite (iron and titanium) and therefore not very suitable for glass-making, according to modern standards. The high iron content is however reducible by simple sieving.

Bangladesh. Md. Alim Biswas[a] has recently reported the existence of glass-making sands in the Sylhet district (formerly of undivided India). These sands have been located in Cochbari, Shilghat and Mirzapur. Upon microscopic examinations, they reveal limonite, magnetite, ilmenite and other impurities. (Composition is given in Table XXV.) Alim Biswas has shown that washing improved the percentage of SiO_2 to 97.8–98.56% and reduced the percentages of Al_2O_3 and Fe_2O_3. After sieving, chemical analyses showed 98.64% SiO_2, 0.36% Al_2O_3 and 0.10% Fe_2O_3 for Mirzapur sand.

If we compare the data of chemical composition of Indian sands, quartz and quartzite with those of some ancient sites in Egypt and Syria-Palestine (Table IX), the quality of Indian sands is clearly seen. It is true that the data of some of the best samples have been included in our Table XXV. As we know, inferior sand after simple beneficiation like washing and sieving—processes certainly known to the ancients—can be much improved through reduction of undesirable iron oxides.

ALKALIES

We have already seen that natural deposits of sodium salts—carbonates, sulphates, chlorides, etc.—due to the drying up and evaporation of land-locked seas and lakes, intentional evaporation of saline water in pits and pans and plant ashes were natural alkalies used by ancient glass-makers in Egypt, Western Asia, Roman Europe and other regions. Natural soda deposits of some Egyptian lakes like Wadi Natrûn and El Kab constituted an important article of trade and were widely preferred by the glass industry because of their high contents of sodium carbonate and bicarbonate.

In India, a soda-bearing substance called *reh* in Bihar and Uttar Pradesh has been in use for the making of glass from ancient times. In its impure state this material itself contains sufficient quantities of silica and lime so as to produce inferior glass when fritted and melted in furnaces. In 1942, when an extensive study of *reh* soils was undertaken by the officers of the Geological Survey of India at the instance of the Board of Scientific and Industrial Research, two bags of crude *reh* material were collected from the jhil area of Lhaksar in U.P. and chemically analysed, to yield the

[a] Alim Biswas; a copy of his paper entitled 'Investigation of some glass sands of Sylhet, Bangladesh', presented at the 62nd session of Indian Science Congress Association, New Delhi, 1975, has been received through the kind courtesy of Dr. S. K. Mukherjee, Member, National Commission on Agriculture, Govt. of India.

following composition: SiO_2—71%, R_2O_3—4.6%, CaO—1.9%, MgO—0.75%, Na_2CO_3 plus $NaHCO_3$—12.21%. The values nearly approach those of the normal ingredients present in glass, and actually an impure glass was obtained by fusing the material collected.[a] With some processing and in admixture with silica and lime, the material is capable of producing glass of some reasonable quality. It is not possible to say how ancient this method might be, but there is hardly any doubt that it had been practised for centuries in many parts of India favoured with naturally occurring glass-making raw materials. This traditional method of making glass from *reh* was found still in operation in many parts of India—for example at Kapadwanj in Gujarat,[b] when, during the 19th and the early part of the present century, possibilities of glass manufacture from indigenous raw materials began to receive the serious attention of the Government.[c]

Reh Soils. Sodium salts are present in all ground waters and attain sizable concentrations under certain conditions. Scanty rainfall, high temperatures, inadequate natural drainage, underground obstructions due to impervious clays, base exchange reactions, are some of the causes of saline soils, surface efflorescences of sodium carbonates and sulphates. Such saline soils are generally called *usar* or barren. And then there are the brine and salt lakes providing important sources of sodium salts.

The *reh* salts occur as thin superficial incrustations, in flaky cemented patches, sometimes in assemblages of small cones, and as a layer of white salt admixed with soil. The thickness varies generally from a fraction of an inch to about 1½ inches. It also occurs in the form of dust in which case *reh* dusts form small isolated patches, but seldom extensive sheets. *Reh* soils are widespread in the Indo-Gangetic alluvial plains from Bihar through Uttar Pradesh up to parts of the Panjab. They are also found in certain parts of Bombay and Gujarat, in Rajasthan, South Arcot, Tiruchirapalli, Chittoor, Guntur, Tumkur, Chitaldrug and other districts of south India, in Baluchistan (Pakistan) and upper Burma.[d] Such salty crusts formed on the surface of the alluvium are called *reh* in Bihar and Uttar Pradesh, as already stated, *thur* in the Panjab, *chowhi chakke* in Mysore and *sapaya* in Burma. *Saji matti* is the name of the crude mixture of sodium salts made out of such soils and sold in the bazars for use as detergents, glass-making, soap-making and various other purposes.

Reh in Uttar Pradesh. Some of the rich *reh* soils are met with in Uttar Pradesh, particularly in the districts of Moradabad and Meerut. Extensive *reh*-ridden tracts occur in the Hasanpur Tahsil of the Moradabad district, stretching across the course of the Ganges beyond its flood limits for about 7 miles.[e] In northern areas, there are almost uninterrupted incrustations glistening white due to their crystalline character. In other areas, specially in the south, *reh* occurs as a loose, impalpable dust, 2 to 3 inches in thickness. In Meerut district, *reh* occurs in three strings, of which the most important is the one in the Loni pargana of the Ghaziabad Tahsil, within 10 miles of Delhi. Here we encounter a rich incrustation, almost continuous and often reaching

[a] Auden, Gupta, Roy and Hussain, 1–2. [b] Dikshit (8), 1–9.

[c] Monographs by Halifax, Dobbs and Mukherjee (TN) on pottery and glass chemistry in the 19th century and Fox's 'Notes on Glass Manufacture' (1923) should be consulted.

[d] Brown and Dey, 512–18. [e] Auden, Gupta, Roy and Hussain, 12–13.

TABLE XXVI
Chemical Composition of Soda Soils—reh and saji matti
(compiled from Auden *et al.* and Brown and Dey)

	Moradabad *reh*		Meerut *reh*		Alluvial soil,	Alluvial soil,	*Saji matti*, Kanpur	*Saji matti*, Dehra Dun
	Hasanpura, Khadar	Average of 4 samples	Hindan	Average of 4 samples	Kanoni, Meerut	Loni, Meerut		
Na_2CO_3	20.26	9.66	9.00	4.68	2.92	0.80	27.02	31.44
$NaHCO_3$	14.04	8.55	9.15	3.96	6.04	1.81	4.28	6.55
NaCl	1.86	1.92	0.92	3.88	0.34	2 43	—	—
$NaSO_4$	9.84	8.66	0.34	1.19	—	3.40	33.98	—

a depth of 3 inches and averaging about 1 inch over the whole area. Other less important *reh* soils in Meerut district include those of Panchli Khurd and Puth Khas near Meerut and of Hindan, 15 to 20 miles from Meerut. In 1942, Auden *et al.* reported the existence of factories for the production of *saji matti* from Loni *reh* by processes of lixiviation and concentration as also evidence of abandoned indigenous 'saji' factories.

Other *reh* areas in U.P. include Muzaffarnagar district, Banaras, Azamgarh, Jaunpur, Ghazipur, Kanpur, Hathras, Mathura, Sahjahanpur and Dehra Dun. All these areas were at one time or another important centres for the manufacture of *saji matti*. Auden, Gupta, Roy and Hussain estimated the annual production of sodium salts from the *reh*-infested districts of U.P. at about 1,400,000 tons, of which sodium carbonate amounted to 500,000 tons, sodium bicarbonate 600,000 tons and sodium sulphate 300,000 tons.[a] The chemical composition of soda soils, *reh* and *saji matti* from U.P. is given in Table XXVI.

Reh in Bihar. In Bihar, Muzaffarpur, Champaran and Saran districts in the north and Nawada in Gaya and the Sheikpura region of Monghyr district have extensive soda efflorescences and have for a long time been well-known centres for the manufacture of sodium sulphate, locally called *khari*. During 1908–23, the production of *khari* totalled 207,850 tons valued at Rs. 49,34,182. The composition is not available, but it is evident that the material was produced by lixiviation of *reh* dust.[b]

Reh from other areas. In Mysore (now Karnataka), *reh* earth has been used to produce crude soda containing 29 % Na_2CO_3, 8 % NaCl. In Mandya, Chitaldrug and Chamarajanagar districts, alkaline *reh* soil efflorescences are situated on granites and gneisses containing soda plagioclase. Sodium carbonate from these areas found its use in the local bangle and tanning industries. Brown and Dey report that an indigenous glass industry existed for at least 130 years at Matrod in the Chitaldrug district, in which local quartz and soda from surface efflorescences were utilized.[c] In Ahmedabad district, *reh* soils occur north of Parantij town, along the banks of the Khari river. The salt incrustations contain sodium carbonate varying from 8.96 to 59.59 %;

[a] Brown and Dey, 515. [b] Auden *et al.*, 29. [c] Brown and Dey, 427.

sodium sulphate from 2.29 to 3.87% and sodium chloride from 2.47 to 15.81%. In Kashmir, small amounts of soda are prepared from alkaline springs, mainly in the Ladakh area. In the Panjab, about 3000 tons of sodium carbonate used to be produced in 1946. But these and adjoining areas now in Pakistan are rich in soda-bearing soils. In Bahawalpur state (Pakistan), earthy sodium compounds mixed with wood ash from a low, green shrub called *Kharr* are found in substantial quantities, mixed with thin layers of sand. *Soudu*, a local name for surface efflorescence of sodium carbonate and sodium sulphate, occurs in the shallow basins of the Yadgir and Makhtal taluks in Gulbarga district, Hyderabad. Soda from these areas has found its use in local industries from very ancient times.[a]

Sodium Compounds from Salt lakes

Salt lakes constitute another important source of sodium salts which found traditional use in many indigenous industries, including glass-making. Some of the important salt lakes include the Sambhar Lake and the Didwana Lake in Rajasthan, the Lonar Lake in Berar and the alkaline lakes of Khairpur in Sind (Pakistan). The Sambhar Lake, the largest in Rajasthan, covers an area of 90 square miles. The lake dries up annually, but the brine formed in the rainy season has an almost uniform composition. The residue after evaporation contains 86% NaCl, 10% Na_2SO_4 and 4% Na_2CO_3. But the bitterns or the mother liquors left behind after the extraction of sodium chloride are rich in sodium sulphate and carbonate as the analyses of bitterns in Table XXVII indicate.[b] When these bitterns are pumped into a reserved area, the East Lake Bitterns area, and allowed to crystallize by natural processes, these are differentiated into a number of layers. The intermediate layers are found to contain exceptionally high percentages of sodium carbonates, bicarbonates and sulphates (Table XXVIII). Auden *et al.* have estimated the Na_2CO_3 and Na_2SO_4 reserve of this lake at 2,300,000 and 5,800,000 tons respectively.

The Didwana Lake in Jodhpur state has an area of about 4 square miles. Analyses of two samples of crystalline pan from this lake area have yielded, in one case, 4.50% NaCl and 82.74% Na_2SO_4 and, in another sample, 0.40% NaCl and 93.17% Na_2SO_4. The Pachbadra salt basin in the Jodhpur state has yielded an impure salt containing 21% chloride and 67% sodium sulphate.

Lonar Lake. Sodium carbonate and bicarbonate, in high percentages, occur in the bed of this remarkable lake situated in the Buldana district of Berar (now part of Maharashtra (Lat. 19°58′45″; Long. 76°34′). Peculiar and picturesque surroundings and physical features of the area in which the lake is located attracted the attention of geologists from the early part of the 19th century. In a communication to the *Edinburgh Philosophical Journal* (**11**, 308, 1824), J. E. Alexander not only described the lake, but drew attention to its importance as a source of sodium salts. He gave a rough analysis of the water, "which was found to contain 37.52 parts of salt, consisting of the 'muriates' of soda, lime, and magnesia, in 100, and a list of the uses to which it was put."[c]

[a] Brown and Dey, 514. [b] Auden *et al.*, 32–35. [c] La Touche and Christie, 267.

TABLE XXVII
Analyses of Salt Lake Bitterns
(percentage)

	Lake salt bitterns		The same on water-free basis	
	A	B	A	B
NaCl	20.26	19.32	61.7	66.1
Na_2SO_4	7.72	6.23	23.5	21.2
Na_2CO_3	3.85	3.69	11.7	12.7
$NaHCO_3$	0.00	n.d.	3.1	×
Water	67.18	70.76	×	×

TABLE XXVIII
Percentage Composition of Bittern Layers—Shambhar Lake

	Layers	B	C	D	E	F	Weighted/ average
	Mean thickness	2¼″	2¾″	½″	2½″	½″	8½″
NaCl		18.8	11.8	100	35 1	61.4	28.6
Na_2SO_4		64 2	21.6	—	49.6	33.6	40.5
Na_2CO_3		10.6	32.0	—	4 5	—	14.5
$NaHCO_3$		4.3	22.0	—	2.8	—	9.1
Moisture by diff.							

The soda deposits of the Lonar Lake and the indigenous methods of extracting the salts have been studied in great detail by F. J. Plymen and W. A. K. Christie. The shallow lake lies in the middle of a circular depression in the Deccan trap, about a mile in diameter and 300 feet deep. The soda is contained partly in the shallow lake and partly in the alkaline mud covering the entire floor of the hollow, and has been worked out for centuries. As the lake gradually dries up and recedes, various layers are exposed as whitish incrustations, crystals, etc. The first incrustation is locally called 'bhuski'; crystals of the first layer which can be hand-collected on further evaporation are called 'papri'; other fragments exposed or easily obtainable with further retrogression are known as 'khuppal', 'dulla' and 'nimak dulla' (also 'dulla nimak').

The chemical analyses of these various fragments are given in Table XXIX.[a] In spite of variations in the chemical compositions of the fragments, the high proportions of sodium carbonate and bicarbonate as well as the consistency in their relative

[a] La Touche and Christie, 277.

TABLE XXIX

Chemical Composition of Different Fragments from Incrustations and Crystalline Mud of the Lonar Lake

	Dulla	Khuppal	Dulla Nimak	Nimak Dulla	Papri	Bhuski
Soluble substances including						
(a) Carbonic acid present as carbonate	19.47	10.00	13.72	4.84	9.62	13.58
(b) Carbonic acid present as bicarbonate	17.38	9.52	13 72	4.49	9 02	14 42
Sulphate as SO_3	none	0.70	0.10	0.08	0.87	0 21
Silica	0.17	0.40	0.33	0 26	0.05	0.30
(c) Chlorine	trace	22.73	14.72	43.25	25.48	2.03
Iron oxides and alumina	0.46	1.21	0.64	0.65	1.47	4.58
Calcium oxide	0.13	0.24	0.24	0.16	0 26	1.35
Magnesium oxide	0.09	0.22	0.21	0.22	0 40	0 39
Soda (as sodium oxide)	33.65	35.17	34.42	44.54	33.36	26.15
Potash (as potassium oxide)	7.14	6.88	9.95	4.28	10.29	5.07
Moisture, water of crystallization and organic matter	20.90	16.03	15.30	6.46	14.71	24.46
(a) Equal to sodium carbonate	46.90	24.09	33.05	11.67	23.19	32.72
(b) Equal to sodium bicarbonate	33.18	18.18	26.09	8.58	17.21	27.53
(c) Equal to sodium chloride	—	37.45	24.25	71.11	41.99	3.35
Total carbonic acid (carbon dioxide)	36.85	19.52	27.44	9.33	18.64	28.00

percentages are remarkable and have been interpreted as the result of crystallization of a compound called 'urao' having the formula $NaCO_3.NaHCO_3.2H_2O$. Some mineralogists have preferred to use the name 'trona' for the compound. Its theoretical composition and the relative proportions of Na_2CO_3 and $NaHCO_3$ in the various fragments are shown in Table XXX, showing the consistency of this important soda-bearing mineralogical product formed in the Lonar Lake.

A perusal of the analytical data given in Table XXIX reveals the presence of potash in appreciable quantities (4.28–10.29%) and small amounts of silica, and oxides of iron, aluminium, calcium and magnesium. In 1910, the alkali contents, in the form of sodium carbonate, of the lake and of its bottom mud up to a depth of 5 feet were estimated at 2000 tons and 4,500 tons respectively. The importance of this soda-bearing lake in a region where chalcolithic sites abound should not be overlooked

TABLE XXX
Relative Proportions of Na_2CO_3 and $NaHCO_3$

	Dulla	Khuppal	Dulla Nimak	Nimak Dulla	Papri	Bhuski	Theoretical
Na_2CO_3	46.89	46 89	46.89	46.89	46.89	46.89	46.89
$NaHCO_3$	33.17	35.40	37.02	34.48	34.80	39.45	37.17
H_2O	19 94*	17 71*	16.09*	18.63*	18.31*	13.66*	15.94

* Balance. Note that the figures nearly agree with the water of crystallization values given in Table XXIX as also with the theoretical value.

in view of the fact that glass in India has now been traced back to chalcolithic times. Even in 1856 two glass factories were in operation near the Lonar soda lake.[a]

Alkaline lakes of Khairpur and Sind. The alkaline lakes, locally called *dhands*, of Khairpur and Sind (Pakistan) are another important source of 'urao' or 'trona'. The double compound of carbonate and bicarbonate of sodium is here known by the name of *chaniho*. G. de P. Cotter, who investigated these lakes, stated that a soda industry based on these *dhands* had existed from time immemorial. These lakes are situated in the depressions among the sand hills. The composition of this *chaniho*, based on 22 analyses, is as follows: Na_2CO_3—37.5 %, $NaHCO_3$—23.7 %, NaCl—4.8 %, and Na_2SO_4—20.0 %.[b] As regards estimates of available trona, Cotter stated, "It is obvious, however, that many of the larger *dhands* contain very large quantities of soda; probably the two largest—Pur Chandar and Kharari—contain each up to 25,000 tons."[b]

POTASH

We have already seen that glass samples from several archaeological sites, e.g. Arikamedu, Nalanda, Ter, Rajghat, Nasik, Kausambi and Taxila, have revealed high potash content upon chemical analysis. Percentages have ranged from 4.83 to 16.12. These percentages compare well with some glass specimens from U.S.S R. and Western Europe of the Middle Ages, where potash-rich plant ashes were used as the alkali in place of soda. In India, the use of potassium alkali prepared from plant ashes appears to be strongly suggested in view of the ancient practice of making this type of alkali from plant ashes. The medical texts, the *Caraka* (c. 100 A.D.) and the *Suśruta Saṃhitā* (3rd–4th century A.D. of the redacted text), clearly distinguish between the sodium alkali (*sarjikā kṣāra*) and the potash alkali (*yavakṣāra*). Regarding the preparation of the latter from plant ashes, Caraka's description is as follows:

> "A young *Butea frondosa* is to be cut to pieces, dried and finally reduced to ashes. The ash is lixiviated with four or six times its weight of water and strained twenty-one times through lime."

[a] Brown and Dey, 427. [b] Auden *et al*, 32; Cotter, 294.

Ray observes that in this way a solution of potash carbonate can be prepared.[a] A more detailed description is met with in the *Suśruta Saṃhitā*.[b]

The Suśruta mentions the following plants whose ashes produce good quality potash alkali: *kuṭaja* (*Hollarrhena antidysenterica*), *palāśa* (*Butea frondosa*), *aśvakarṇa* (*Shorea robusta*), *paribhadraka* (*Erythrina indica*), *vibhītaka* (*Terminalia bellarica*), *āragbadha* (*Cassia fistula*), *tilvaka* (*Symplicos racemosa*), *arka* (*Calotropis gigantea*), *snuhi* (*Euphorbia nerifolia*), *apāmārga* (*Achyranthes aspera*) *paṭala* (*Stereospermum suaveolens*), *naktamala* (*Pongamia globra*), *vriṣa* (*Justicia adhatoda*), *kadalī* (*Musa sapientum*), *citraka* (*Plumbago zeylanica*), *puṭika* (*Guilandina bonducella*), *indravṛkṣa* (*Terminalia arjuna*), *asphoṭa* (*Salvadora persica*), *aśvamaraka* (*Nerium odorum*), *saptacchada* (*Alstonia scholaris*), *agnimantha* (*Premma serratofolia*), *guñjā* (*Abrus precatorius*), and four sorts of *koṣa* (*Luffa amara*).[c] The method of preparation is given as follows:

> "With due religious ceremonies some trees or plants are cut to pieces on an auspicious day in autumn by the worker. These pieces are piled in a place free from wind. Some limestone should be placed on the pile and then set on fire by stalks of a selected plant. When the fire is extinguished, the ashes of the tree and the burnt lime should be kept separate.
>
> "Thirty-two seers of ashes should be stirred or mixed with six times their quantity of water and the mixture strained through cloth. This should be repeated twenty-one times. The strained fluid should then be boiled slowly in a large pan and agitated with a ladle. When the fluid becomes clear, pungent and soapy to the feel, it should be removed from the fire and strained through cloth. The dregs being thrown away, the strained fluid should be again boiled. From this alkaline solution take three quarters of a seer.
>
> "Then take eight palas each of burnt limestone, conchshells and bivalve shells, and heat them in an iron pan till they are of the colour of fire. Then moisten them in the same vessel with the above-mentioned three quarters of a seer of alkaline water and reduce them to powder. This powder should be thrown on sixty-four seers of the alkaline water and boiled with constant and careful agitation by the ladle. Care should be taken that the solution is neither too thick nor thin.
>
> "When reduced to proper consistence, the solution should be removed from the fire and poured into an open jar. The opening or mouth of the jar should be covered and should be kept in a secluded place. This preparation is called *madhyama kṣāra* or alkaline caustic of middling strength.
>
> "When the alkaline water is simply boiled to the proper consistence without the addition of burnt shells, etc., the preparation is called *mṛdu kṣāra* or mild alkaline solution.
>
> "The strong alkaline caustic, i.e. *tikṣṇa kṣāra*, is prepared by boiling the weak solution with some dried plants in the form of powder."

[a] Ray (PR), 62. [b] Ray (PR), 63–64.; c. SS. [c] Ray (PC), I, 19–20.

Some of the plants which yield good quality sodium and potassium carbonates are enumerated in the *Rasārṇava* (12th century A.D.) in the following terms:

> "The three alkalies are the borax, trona (natron) and *yavakṣāra* (carbonate of potash). The ashes of sesamum, *Achyranthes arpera, Musa sapientum, Butea monosperma, Moringa pterygosperma, Schrebera swietenioides, Raphanus sativus, Zingiber officinale, Tamarindus indica* and *Fiscus religiosa* respectively are regarded as the standard plant ashes."[a]

Potassium of course occurs in the form of compounds and minerals in various parts of India. In saltpetre (KNO_3) India at one time held a virtual monopoly of the world's supply of nitrates. KNO_3 is formed wherever organic, nitrogenous substances decay in contact with potassium salts, due to the activity of nitrifying bacteria. Natural formation of saltpetre has been noticed in areas of dense population using wood and cowdung as fuel, where humidity and temperature favour the growth of microorganisms. Rich sources of natural saltpetre include the Gangetic districts of Bihar—Muzaffarpur, Saran, Champaran, Darbhanga, Shahabad, Gaya and Monghyr; Kkanpur, Ghazipur, Allahabad and Banaras districts in U.P.; and Amritsar, Lahore, Hissar and Multan of undivided Panjab. The districts of Anantapur, Coimbatore, Guntur, Kurnool, Madurai and Nellore in the south and Ahmedabad district of Gujarat also produced small quantities of saltpetre.[b] Potassium-bearing minerals such as langbeinite, a double sulphate of potassium and magnesium ($K_2SO_4.2MgSO_4$), have been found in the Mayo Mines of the Panjab Salt Range. But it is not certain to what extent, if at all, such naturally occurring potassium salts found their use in ancient Indian glass-making industries.

Other Raw Materials

LIME AND MAGNESIA

Making of lime by burning limestones and shells is an ancient practice. The great group of calcareous rocks are formed of limestones, chiefly of calcium carbonate. This carbonate exists in crystalline forms, such as calcite and also in the form of chalk, marl, *kankar* and Tufa. With the exception of the crystalline transparent variety, the Iceland spar, limestones are seldom pure and usually contain sandy argillaceous and ferruginous constituents. The double-carbonates of calcium and magnesium, $CaCO_3.MgCO_3$, called dolomite, or dolomitic limestone, also constitute an important source. Limestones are widely distributed in India,—in Bihar, Orissa, Madhya Pradesh, the Deccan trap, Nawanagar, Saurashtra, Rajasthan and Andhra Pradesh, to cite a few. An average of analyses of limestones from Rajasthan, Uttar Pradesh, Panjab and Mysore shows as follows: CaO—44.48–55.14%; MgO—0.11–2.91%; Al_2O_3, Fe_2O_3—0.15–4.30%; SiO_2—0.14–15.95%.[c]

In view of the suspected use of dolomite in ancient glass specimens as elsewhere, a few words may be said about its occurrence in India and its composition. Geologists

[a] Ray (PR), 137. [b] Brown and Dey, 467–68. [c] Brown and Dey, 335.

TABLE XXXI

Analyses of Indian Dolomites

District	Locality	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Loss on ignition
Sundargarh (Gangpur)	Birmitrapur	2.95	1.30	0.80	30.58	19.55	44.35
Sambalpur	Sulai	3.40	0.02	0 78	29.68	20.41	45 46
Bilaspur	Akaltara	4.03	1.12	1.20	30.22	18.91	44.13
Shimoga	Shankargudda	2.60	4.00	1.55	32 01	16.72	43.17
Jodhpur	Bilara	0.44	0 32	0.26	31.02	20.72	—
Mewar	Rajnagar	—	—	—	32.67	21.09	41.09
Chhota Udaipur	Deohati	1.38	0.52		30.03	21.22	46.58
Dehra Dun	Mussoori	0.20	1.62		29.95	20.85	46.72

maintain that ordinary limestones are changed into dolomitic limestones and dolomites by the long continued action of magnesium salt solutions. Sedimentary and infiltration dolomites occur in the later formations of all ages from the Palaeozoic to the Tertiary. Good quality dolomites occur in Birmitrapur, and Gangpur in Orissa, Putuda and Palamau districts in Bihar, in the famous 'marble rocks' of the Narmada gorge in Jubbulpur district, and in Betul, Chhindwara, Nagpur and Seoni districts, in Rewa and Dhar districts of Madhya Bharat, in the Pakhal series of the Warangal, and in Rajasthan. The whole length of the Himalayas from Kashmir in the west to the Dihang valley in the east abound in dolomite deposits. Some analyses of Indian dolomites are given in Table XXXI.[a] The ratio of CaO/MgO lies between 1.4 to 1.9 in these samples.

FELSPARS

These are alumino-silicates of sodium, potassium, calcium and a few other elements. Their important varieties are orthoclase, microcline and albite, the former two being potassium aluminium silicates and the last sodium aluminium silicate. Felspars constitute the most abundant rock-forming minerals and are widely distributed in India. Their principal occurrences include the mica-bearing pegmatites of Ajmer-Merwara, Mewar and Alwar in Rajasthan, Gwalior state in Madhya Pradesh, Saurashtra and Bombay, mica-bearing areas of Koderma, Bhagalpur, Gaya, Manbhum and other places in Bihar, pegmatite vein at Shettihalli near Chickbanvar, Nellore and Tiruchchirapalli. Felspars are used in the manufacture of pottery, porcelain, ceramic glazes, vitreous enamels and glass. Indian felspars from various sources have been analysed.[b] Its principal constituents are: SiO_2—between 64% to over 70%;

[a] Brown and Dey, 403.

[b] Brown and Dey, 380–88; Atma Ram, Karimullah, Saboor and Verman, 190–95.

Al_2O_3—between 14% to 24%; Na_2O—between 3.02% to 11.62%; K_2O—between 0.12 to 14.48%. The high and small percentages of alkalies depend on the type of felspars, $K_2O.Al_2O_3.6SiO_2$ or $Na_2O.Al_2O_3.6SiO_2$. Other oxides present in small quantities, within 1%, include Fe_2O_3, MgO, CaO, and TiO_2. If felspars were used in ancient Indian glasses, as suggested by some analysts, these had also contributed to the silica, alkalies and other oxides found in these glasses.

CHAPTER IV

FURNACES, TOOLS, AND TECHNIQUES FOR FASHIONING GLASS OBJECTS

As in the case of raw materials and methods of manufacture of glass, there is little information regarding furnaces, tools and various techniques employed by ancient Indian glass workers for fashioning their glass objects. In spite of numerous references to glass objects and their uses in many literary works, as we have already noticed, there is precious little to be found in them about these techniques. Here also the very glass specimens and objects unearthed at different archaeological sites, after proper scientific examination, themselves provide indirectly some idea about these techniques, e.g. the furnaces likely to have been used, the temperatures of smelting as well as working with glass, modelling, moulding, blowing, annealing, and the tools used. The techniques of potters which are widely believed to have been more or less adopted by the glass makers and workers, with necessary modifications required by the nature of the material itself, furnish another useful guide. And then we have the account of techniques, presumably followed from very ancient times, still practised in some indigenous glass-making centres, to throw some light on the subject.

FURNACE, OVEN AND GLASS-POT

In India, the glass wares that have been unearthed from various archaeological sites are mostly beads, fragments of bangles, tiles, etc. George Watt has remarked that India, with her abundant glass-forming and glass-making constituents, did not advance beyond the first and the very rudimentary stage. As a result of the employment of too much alkali and little heat, the finished material is a coarse, impure dirty-coloured mass, full of flaws and air-bubbles, unfit for better use than the manufacture of beads, coarse bangles, other minor and unimportant articles. From an early period (i.e. during the time of Mohenjo-daro), charcoal was used as fuel and the heating temperature could not be more than 1000°C. Even at a much later date in the sixteenth century and still later the glass industry in India had not advanced beyond the crude stage, due primarily to the inefficiency of Indian furnaces, which were incapable of producing a sufficiently high temperature. As a matter of fact no remarkable progress took place before the last quarter of the nineteenth century even when indigenous production on a small scale was restricted to a few localities in the Punjab, U.P., Bihar, Bombay, Rajputana, and the chief articles of manufacture were bangles, beads, small bottles and crude toys.[a]

FURNACE, OVEN

During the centuries before the middle ages, in almost all parts of the world we

[a] Dutta, 235; Watt, 3, 502.

have a poor and incomplete picture of glass furnaces. The oldest and simplest form of furnace is, in effect, a box built of firebrick in the centre of which stands the crucible, while piles of wood or coal are placed on either side. To attain any degree of heat by such means, however, the size of the box or chamber and especially of the gates in which the fire is maintained must be properly proportioned both to the dimensions of the crucible and to each other. The gates are generally wide and deep while draught is provided by means of the tall conical chimney, which stands over the entire chamber and communicates with it by a number of small openings. In a more improved furnace the chamber itself is double, and the flame, after playing around the crucible in the inside of the chamber, is made to pass through the space between the outer and the inner chamber before passing to the chimney or cone.[a] Petrie has given a description of an original furnace discovered by him at Tell-el-Amarna (Egypt) dating back to about 1350 B.C. It was a shallow clay pan about 10″ across and 3″ deep, in which fritting or subsequent proper melting took place over a charcoal fire in a hearth pit. The heat for melting the glass in shallow dishes or small crucibles was supplied by brazier firing or an open fire akin to a blacksmith's forge. This means that glass had to be worked at a relatively low temperature, perhaps 500°C below that at which glass is now blown. It could be pressed and moulded, but the possibilities of production of hollow ware were very limited. Glass furnaces mentioned by Pliny were probably small beehive-shaped hearth furnaces with one or two compartments for a small crucible and again one or two small compartments left empty for cooling or annealing of blown objects. The furnaces in glass factories grew more and more elaborate during the course of centuries. Roman glass-furnaces were found at Wilderspool near the Mersey, where six furnaces stood (some in pair) on a platform. They had an oval or rectangular section and were originally domed. One of the oval furnaces was divided into three parts by a floor below the fire-place. Thus different degrees of heat could be achieved and the lower floor probably served for cooling and annealing vessels. A large canal passed right through the three platforms and probably served to equalize and regulate temperature. In front of each furnace there was a floor consisting of a limestone slab used for marving and other operations.[b]

Regarding the glass furnace in ancient India, our information is, however, meagre. The descriptions of the furnaces that we find in the report of the excavation at Mohenjodaro are mostly of those used for pottery making, of which a large number have been unearthed. But most of them resemble those of Egypt already described. A glass-making kiln,[c] the description of which has been recorded in the report of the archaeological excavation at Nevasa, is dated about 3rd to 4th century A.D. It is a circular oven of 2′6″ in diameter with 1′7″ in depth and is made of burnt clay. Around it was found an abundance of bichrome glass, slag lime, cowdung, etc. (Fig. 6).

The excavation at Lothal, in the Gangetic valley, reveals a circular furnace[d] of 6″ in diameter, with a hanging roof having four openings. The surface of the oven

[a] Rosenhain, 60. [b] Forbes (5), 117–18. [c] *IAR* (1959–60), 25–26.
[d] *IAR* (1957–58), 12.

is plastered with mud. It might have been used for heating the raw bead-material and half-finished beads (Fig. 7).



Fig. 6—Glass-making kiln at Nevasa.

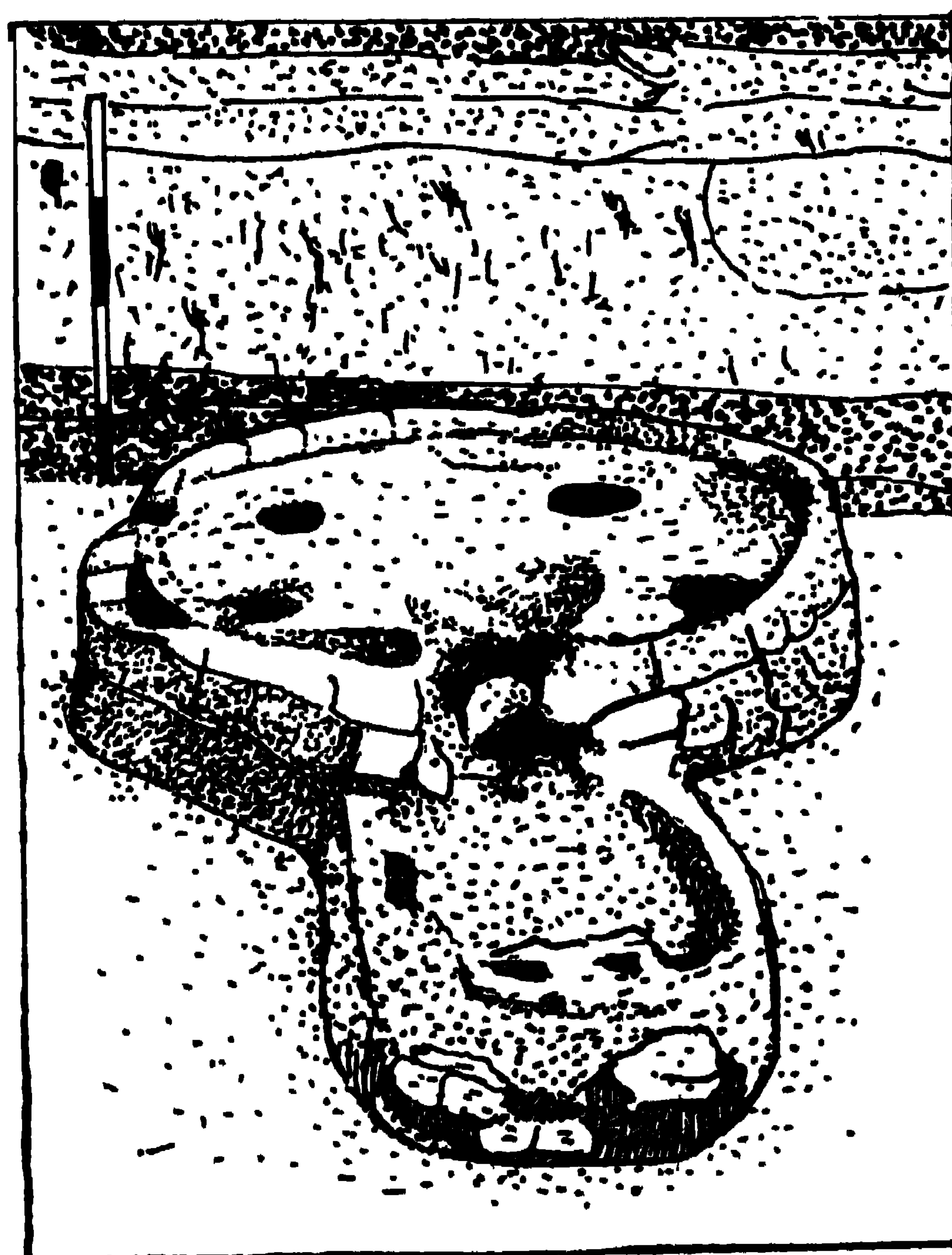


Fig. 7—Glass-making furnace—Lothal.

It has been remarked by C. S. Fox that most of the glass furnaces in ancient India are open-fired type, using solid fuel, and melting was carried out in clay pots.

It might however be pointed out here that evidence of large scale glass-making at a much earlier date, e.g. in Kopia (5th century B.C.), Taxila (7th century B.C.), Maheswar, Navdatoli, Nevasa, etc., has been obtained as a result of archaeological excavations at these places, as stated before (vide Chapter II). It is quite likely that the more improved pattern of kiln using a clay pot might have been employed at those places.

GLASS POTS AND MUFFLES

As regards crucibles our evidence is very meagre. At Mohenjo-daro[a] we have found several pieces of pottery that appear to have been used either in connection with a kiln or, in one case at least, as a crucible (Fig. 8). One is thickly coated with a mixture of sand and clay, and there is no doubt that it was used as a pot for melting glass. Mackay is of the opinion that it served either as a crucible or, more likely, as a muffle for firing glaze in a thin pottery plate, 4.17″ in diameter and 0.2″ in thickness. It has a thick cement of mud and straw round the edge which shows signs of burning. This plate was evidently used to seal up the flue of a furnace. Similar plates with a similar cement are used for the same purpose in India at the present time. A small open vessel, which was found with two others of the same shape and size, is covered with a grey paste that was heavily fired, apparently more than once. This vessel, which has a fairly smooth interior, though with a rough outside, may have been used as a kind of muffle.

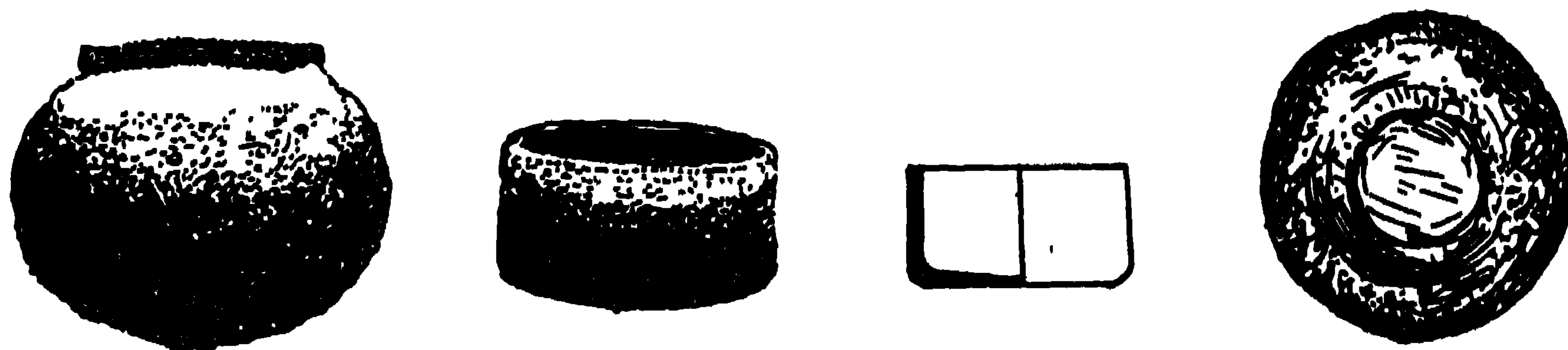


Fig. 8—Glass pots and muffles—Mohenjodaro.

Specimens unearthed from Kopia,[b] about 31 miles from Basti in Uttar Pradesh, include beads of numerous shapes, sizes and patterns, lumps of glass separately and also sticking to pieces of what can easily be recognized to be parts of some clay containers or crucibles which might have been used for the heating or melting process. Dr. M. N. Nagar, Curator of the Provincial Museum at Lucknow, is of the opinion that the mound of Kopia (extending about a mile and rising about 40 ft from the surrounding fields), scattered over with innumerable glass beads and glass pieces of various shapes and sizes, was the site of an ancient glass factory of about 5th century B.C. The clay pieces, supposed to be parts of containers or crucibles, are reddish brown in colour, hard and stone-like to touch, and when examined in section appear to have

[a] Mackay (2), 1, 177. [b] Roy and Varshney, 366–68; 392.

characteristic structure. From the appearance of these pieces one gets the impression that perhaps a lateritic clay was used for making them, and on verification this proves to be a close-grained, hard reddish brown, stone-like body. The numerous small pitted pots or cavities are clearly seen to be due to the presence of organic matter, which got burnt out when the crucible or pot was fired. An examination of the surface of some of these cavities with small pit marks under moderate magnification showed a regular check pattern made up of one set of parallel furrows running at right angles to another set. From this pattern it is evident that pieces of cloth were pounded and used in the clay mixture in order to give strength to the crucibles while they were being made. When the clay body was heated in the furnace, the pieces of cloth or rags got burnt leaving a cavity in which the characteristic texture of cloth was imprinted on the clay surface. In some of the clay pieces one side (viz. the concave side, which may well have formed the inside of the crucible) had a black glazed surface while the other side had the rough appearance of a hand-moulded clay article. Of the two other pieces of such broken terracotta crucibles or containers, the upper and larger piece shows what may well have been the spout of the crucible. The material sticking to it had apparently suffered more deterioration than other lumps of glass and it was perhaps the originally sintered glass batch which had not been thoroughly melted.

Some specimens of glass were discovered in 1938 in Dargai village in the Malkand Agency (N.W.F.P.) along with an earthen pot, probably employed for manufacturing glass.[a] The discovery of the crucibles along with the varieties of specimens undoubtedly gives a clue to the existence of a glass industry at the place.

Tools and Implements

Tools[b] for working molten glass for bangles and bowls being used in India at the present time by workers in the countryside are as follows:

Ankri, adhkar, unkri or *upri.* This is an iron rod about two feet long, hooked at one end and fixed on to a wooden handle at the other. It is used for stirring the molten glass and taking it out of the crucible.

Aarag, sallakh or *suja.* This is a long pointed spit of iron of uniform thickness.

Mala, bala, thapi or *pathia.* This is a moulding and pressing tool of iron, shaped in some districts like a big spoon, which is used for taking out metal, while in some other districts it is shaped as a heavy blunt dagger.

Tokla. It is an iron rod with a thick butt tapering off to a point.

Bardhana, barauna, bidarka or *unar.* This is a short piece of stout iron wire fixed into a light bamboo handle at one end and sometimes hooked, sometimes straight, at the other end. It is inserted between the inchoate bangle to prevent its sticking to them.

Chitarna. This is an iron rod used in Saharanpur and Etah for twisting the molten glass for certain kinds of bangles.

Kalchul or *karchuli.* This is an iron ladle used for transferring the molten glass from one crucible to another.

[a] Lal (Dr) (1), 24. [b] Dobbs, 36; Hallifax, 24.

Kalbul, sundar, surtàri. This is a clay cone fixed on to an iron handle for shaping the bangle. In the Punjab the instrument is called *sarbandi* and *salendhi, sarkandi* or is known as *kalbut.*

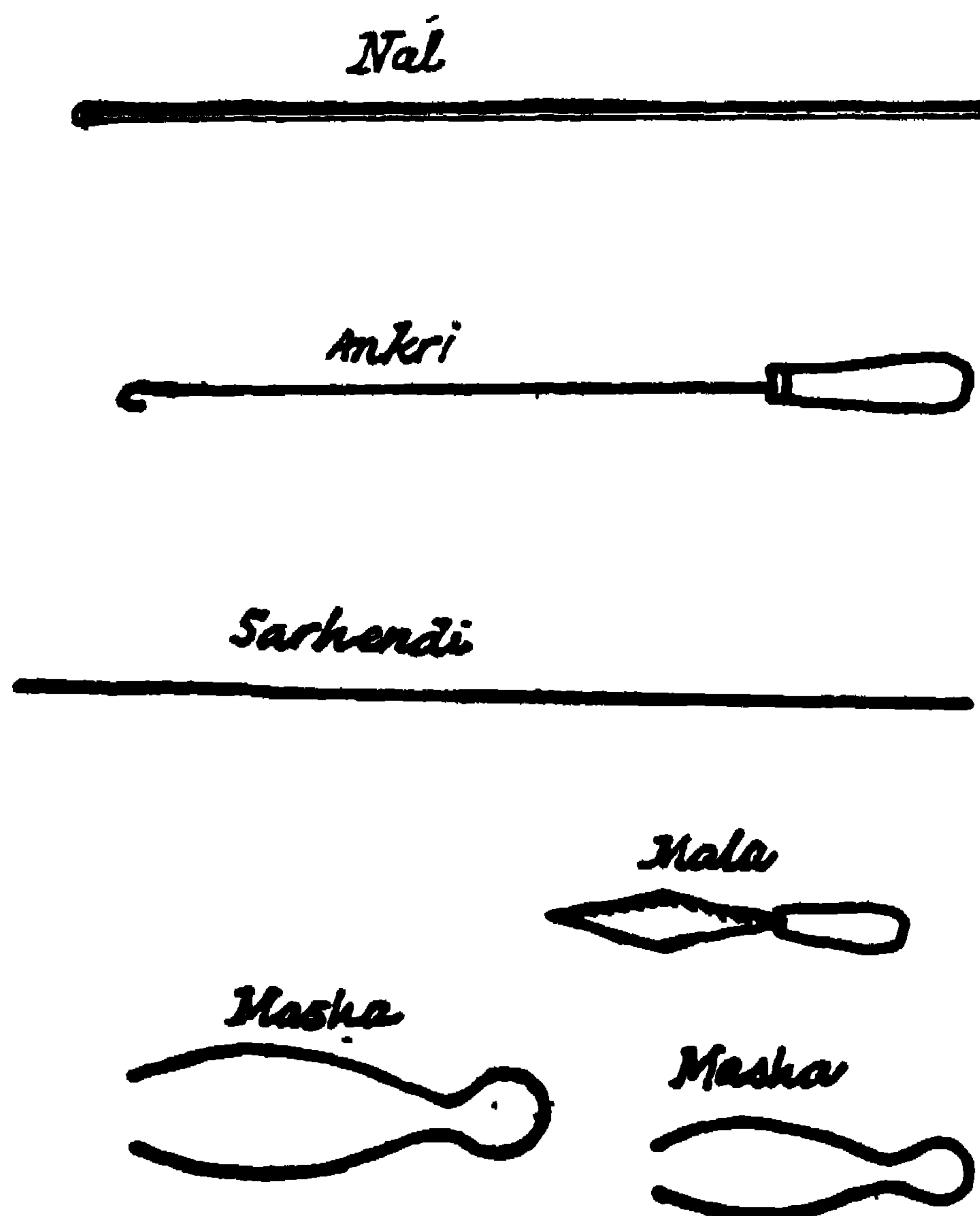


Fig. 9—Some of the instruments used in glass-making.

Tools[a] for blown articles include:

Nal, phunka, or *dhotali.* An iron blow-pipe, usually a piece of an old gun-barrel.

Kund, or *sarhendi.* A solid bar of iron which is attached to the bottom of the bubble of glass when blown.

Mala. A dagger-shaped pressing instrument.

Masa or *masha.* Pincers of stout iron wire, shaped like a big hair-pin, used for working the rough edges of an article to shape and separate it from the blow-pipe.

Chimla or *ambar.* Broad iron tongs for placing broken pieces of glass in position in the furnace.

Sikh. Iron spit for stirring the melting glass.

Sil. Slab of stone on which the end of the blow-pipe is rolled round the squeeze together with the pieces of glass picked up.

It is not unlikely that tools of similar shapes were used for the same purpose in ancient India.

TECHNIQUES

MODELLING

The earliest glass vessels were modelled[b] on a sandcore. In such a process the

[a] Dobbs, 42. [b] Harden (1), 420; Singer, 2, 334.

glass batch (the raw ingredients of the glass before fusing) was fused in a clay crucible and allowed to cool, the defective parts were chipped off and discarded and lumps of metal (unworked glass after the fusion of the raw materials) were reheated so that it might be rolled out into rods. A core of sand was affixed to a tapering metal rod, and the vessel was modelled by winding the glass rods spirally round this core. The surface was then smoothed by marving or rolling the glass on a smooth surface. When the vase was complete the metal rod and core of sand were removed; examples of this early glass almost always show a coating of sand on their inner surface, an indubitable proof of the technique employed. This process is troublesome and ill-suited to the production of large vessels.

MOULDING

In this process the molten glass is poured and pressed into a mould.[a] The ancients from very early days understood the use of moulds for objects of clay and metal. They also adopted this process for glass. The production of glass in a crucible would show that when cold, it took the shape of a crucible.[b] Among the glass specimens of ancient India like beads,[c] the heavier or larger objects were made by moulding. In their devitrified state the irregular masses in the structure clearly indicate this feature in early glass. It is not possible to get a correct idea about the material for these moulds. It was sand moulds which could naturally be destroyed when the objects enclosing them were extricated. But it is also possible that some of them were of reddish sandstone. Many examples of these were found at Ter and Paithan.[d] At Prakash[e] the monochrome translucent variety of glass bangles with pentagonal sections seems to have been manufactured by the use of moulds. A flattish tile with depressions for square beads is derived from Kolhapur also. At Kondapur[f] beads were made by taking two shades of pale blue glass and swirling with a layer of milky white opaque glass between them. These were then moulded into a bead. This left a brilliant white zonal line in the central portion. It is possible that these moulds were used by goldsmiths for repousse work in metals; but those intended for glass may not have been far different.[g]

BLOWING

The next development in the glass industry was the invention of glass-blowing towards the end of the first century B.C. It was the most revolutionary development ever made in the history of glass ware. It is quite natural that the invention of glass-blowing began by blowing glass into a mould and was then developed into free blowing. The fragments of a very fine bowl of the 1st century B.C., discovered at Taxila, reveal its preparation. This was made by taking canes made of threads of white and colourless glass, which had been twisted together so as to form a spiral and then winding the canes, when plastic, round the inside of a mould and fusing them together with heat and pressure. To form the rim a piece of blue and white glass had been used.

[a] Harden (1), 421. [b] Singer, 2, 334.
[c] Sankalia *et al.*, 356; Dikshit (5), Beads No 188, 193. [d] Dikshit (9), 55.
[e] Thapar (2), 4–167. [f] Dikshit (5), Beads No. 188, 193, 203. [g] Dikshit (5), 55.

This method was employed extensively by the Romans, and many similar specimens have been found at Pompei and other sites. This technique was at a later date developed very extensively at Venice, and such glass was called *vitro di trina* or lace glass.[a]

The process of blowing[b] is practically the same in both European and country glass. The following is a description, as given by Dobbs, of the making of glass pickle-jars or *achari* at Lucknow during the eighteenth century.

There are two workmen engaged at the furnace. A broken tumbler is placed on the floor of the front melting compartment or the edge of the hole through which the flames of the fire are shooting up. After about five minutes the first workman takes it up with the tongs and attaches it to the end of the blow-pipe, which he has previously smeared with a gum made of salt-petre, borax, arsenic and water. He then hands it on to the second workman, and receives from him a second blow-pipe with a fused mass of glass attached to its end, which he will blow and shape while the fragment of the tumbler is in the hands of the second workman. The latter holds the fragment of the tumbler over the fire at the end of the blow-pipe for about five minutes until it is thoroughly fused, when he takes it out and rolls it round on the stone slab, patting it into a round ball with a dagger-shaped tool called *mala*. After this he plunges it into a jar of water to cause all the air bubbles to escape, and fuses it again over the flames for another five minutes. He then hands it over to the first workman, who warms once more and then blows into the pipe for about ten seconds till a bubble one inch long protrudes from its end. He repeats this warming and blowing process three times until the bubble is four inches long. Then he places the blow-pipe on the grooved rest in front of the furnace so that the bubble of glass is over the flames, and twirls it rapidly round in order to get the shape even. After this he swings the blow-pipe twice round his head elongating the bubble by centrifugal force, and warms it again. This swinging and warming process is repeated five times. He then flattens out the bottom of the bubble by pressing it against the side of the furnace. Next he takes the *kund*, a solid bar of iron, and sticks it into the centre of the bottom, making the bottom rise into a cone inside the vessel. The glass bulb is now held between the blow-pipe and the iron bar. The workman next takes the tweezers of stout iron wire, dips them into water and grips the stem of the bulb with tweezers just at the point where the blow-pipe inside the stem ends. The stem cracks round this line under the touch of the moist tweezers and the blow-pipe is left with about three inches of neck round its end, while the main body of vessel is stuck by its bottom to the iron bar. The fragment on the blow-pipe is knocked off and put among the broken glass to be melted up again. The workman now turns the iron bar, to which the incomplete vessel is fixed, on the socket in the screen before the furnace, until the rim is well warmed. He then takes it out and works the tweezers about inside the rim of the vessel till he has got it into the proper shape. The vessel is then cooled for four hours in each of the three annealing ovens. An article such as a lamp globe or a lamp chimney, which is open at both ends, is not put into the annealing ovens, as the quick contraction in the cool air does not cause it to crack. In ancient India, a few specimens of blown wares in the form of flasks of sea-green or jade-green colour have been found at the

[a] Beck (4), 21. [b] Dobbs, 42–43.

Sirkap site, belonging to the late Śaka-Parthian age. The process of blowing in those early days was possibly somewhat simpler and cruder, though resembling that described by Dobbs, than what was in vogue in the eighteenth century.

ANNEALING

Nearly all kinds of glass ware, in the normal processes of their manufacture, develop a condition of strain as a result of too rapid cooling. In many cases this is very great, and in others it is not so, but, at the same time, the finished article would be easily destroyed if put to ordinary usage for which the articles were made. Consequently there are very few kinds of glass ware which do not require annealing subsequent to the operations involved in their manufacture. This removal of strain is effected by allowing the highly treated prepared article to cool slowly to a lower temperature of about 500°C.[a]

PROCESSES OF MAKING BEADS, BANGLES, VESSELS, ETC.

BEAD

A large number of various types of beads have been unearthed by archaeological excavation at different sites, which appear to be prepared by the use of different processes like twisting, wire-wind, moulding from canes, folding, double-strip method, etc., according to their designs. These are eye-beads, gold-foil glass, red glass with white or black core, millefiori glass, composite glass (black and white). Beads made by using together differently coloured glasses have also been found. The technical skill and the artistic ideas of the craftsmen are revealed in the choice of coloured glass.

A bead can be more or less fully described by mentioning its form, perforation, colour, material and decoration. But according to some the method of fabrication[b] of a bead is of foremost importance in describing its characteristics.

METHOD OF FABRICATION

In an iron container a mixture of powdered quartz or very pure sand with alkali (soda, potash or nitre) and some lime in quantities is heated to fusion to form a uniform molten mass. Generally before heating, colouring materials like minerals containing iron, copper, manganese, cobalt, etc. were added. When all these were thoroughly mixed and melted into a thick syrupy mass, a workman stirs it with an iron bar on the end of which he gathers a viscous mass of red hot glass. After this he fixes another bar in the mass and gives that bar to a second workman, who runs with it at full speed, pulling the glass mass out into a rod, which solidifies instantly by cooling and appears as a shiny rod, twenty-five to thirty yards long, half an inch thick near the base and thinning out to perhaps $\frac{1}{20}$ of an inch in the middle. This long rod is then cut down to handy lengths of two or three feet. These glass rods or sticks are the raw materials for making the oldest and simplest kind of beads, the so-called wound beads (Fig. 10).

Wire-wound beads. For preparing such beads[c] the workmen melt one of these

[a] Fox, 42. [b] Sankalia *et al.*, 369; Van Der Sleen, 204ff. [c] Van Der Sleen, 205.

glass rods at one end and then fold the softened rod into ring round a copper or iron wire which they hold in the other hand. When the glass ring is closed round the wire, the rest is cut off and the wire with the glass ring turned and heated till it is nicely round or oval. When three or five rings have been turned round the wire it is laid aside to cool. In cooling, the metal contracts more than the glass and the beads can be stripped off, especially as the wire has first been turned round in ashes and fine sand. According to the diameter of the wire, a wide or narrow perforation can thus be made in the bead. When the wire tapers, the perforation will also be tapering, which was often the case in the olden days. Then too, the heat often was not strong enough to melt a thick rod of glass and beads were made by winding a rod of 1 or 2 mm diameter several times round the tapering wire or other core (multiple winding) (Fig. 11).

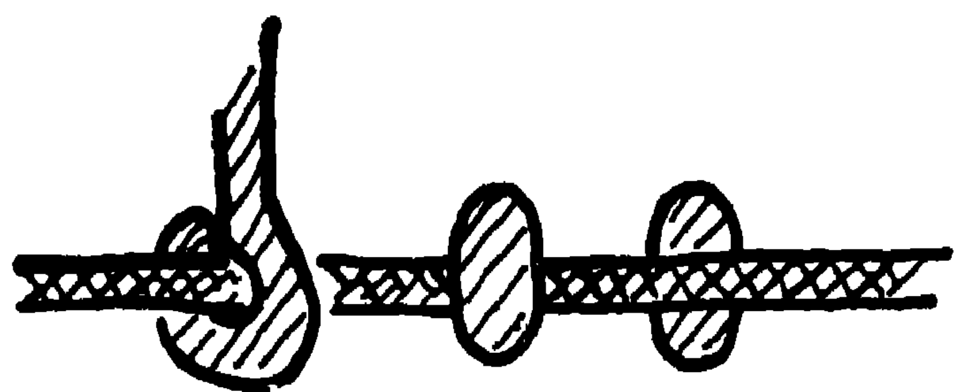


Fig. 10—Simple-wound bead.

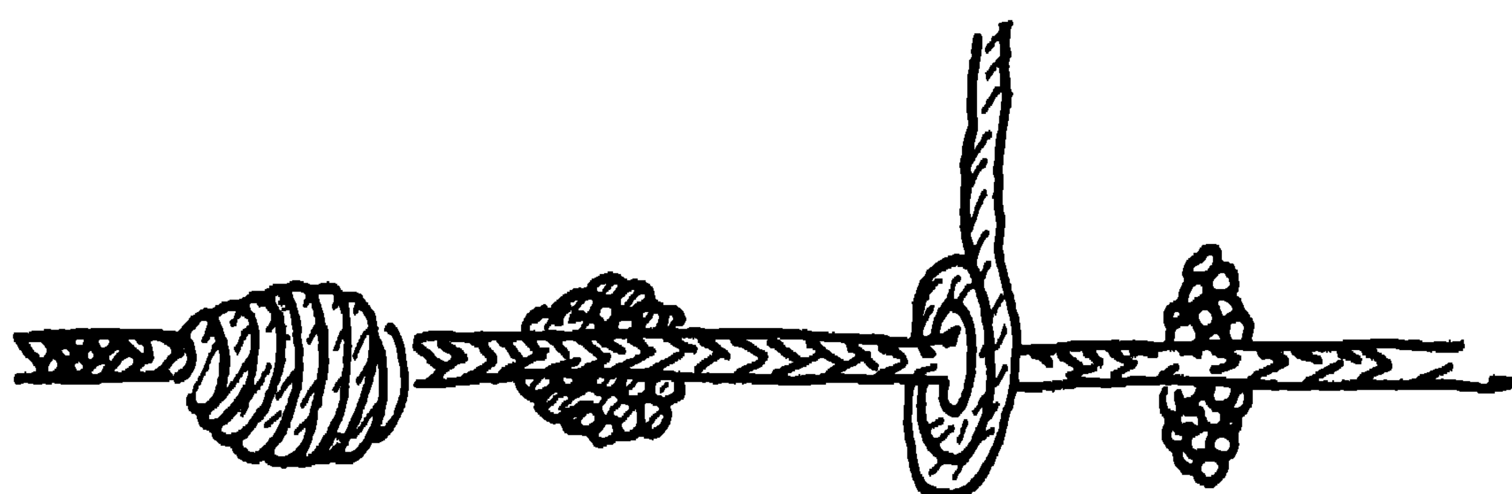


Fig. 11—Multiple-wound bead.

At Brahmapuri,[a] several beads seem to have been made by the wire-wound process by coiling the softened glass rod around a spoke and twirling it to a requisite shape. Disc beads with a lens-shaped cross-section are found to have been made in this way to a very large extent. Careful tooling was required for shaping them into square barrel, square, bicone, globular beads and even hexagonal cylinders. In the wire-wound process, the trailing of the glass thread is generally quite perceptible on close examination, but in the twirled beads the masses seem to be homogeneous. In all the Indian specimens the wire around which the glass was wound was invariably a stationary one. This is in sharp contrast to certain beads made in Japan where the rod itself is made to revolve around its axis mechanically, leaving quite a smooth surface in perforations. Cross-sections of Indian wire-wound beads show that they have a rough unfinished surface in the core of the perforations and thus indicate that the process of fabricating such beads was a very slow one.[b] (Fig. 12).

Multiple wound beads of opaque glass. The multiple wound beads[c] of differently coloured glasses were known in India from the first few centuries of the Christian era. From their appearance it is clear that the craftsmen who made such beads were well acquainted with the technique of making multiple wound beads of differently coloured glass through transfer of one variety of opaque coloured glass to another. This also involved the knowledge of making a thin rod by pulling out a lump of semi-molten glass. Two varieties of shapes of these beads are noticeable: (1) globular and oval which sometimes develop into long biconals; (2) short bicones, which look sometimes almost lenticular. Both types are practically made of opaque glass in black, Indian

[a] Sankalia and Dikshit, 100. [b] Dikshit (9), 56. [c] Van Der Sleen, 210–11.

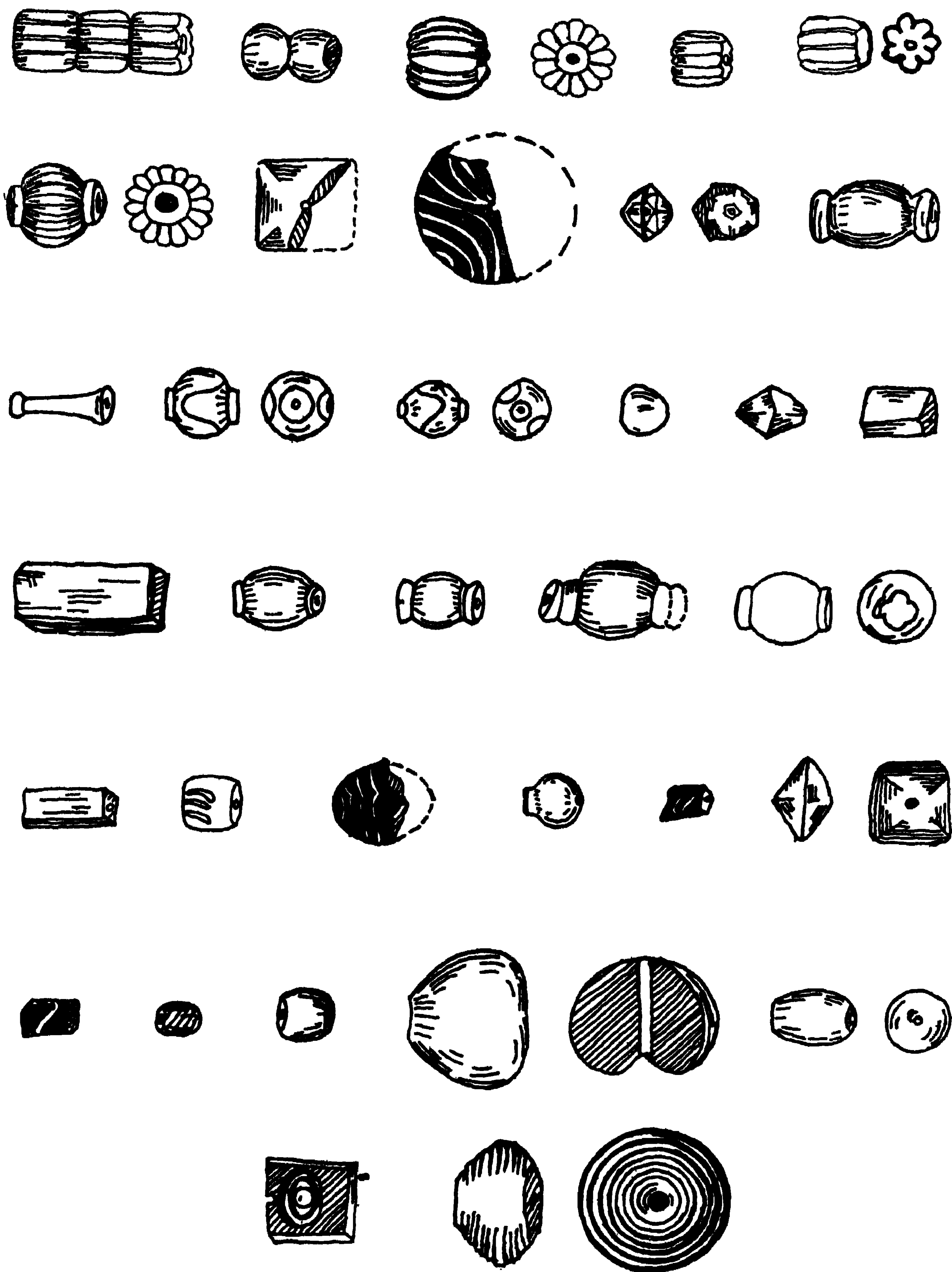


Fig. 12—Wire-wound beads at Brahmapuri.

red, yellow, green and rarely blue. Another characteristic feature of these beads is that they have a tapering perforation which is an important distinction from the Egyptian short biconal beads, where the perforation is uniformly wide.

Such multiple wound beads both of globular and lenticular types have been found in large numbers at Brahmapuri and the old town of Kolhapur in Maharashtra State (Fig. 12). The excavation of the site shows that there must have flourished a glass industry of lenticular beads during the Sātavāhana period (Andhra period) dated from the second century B.C. to second century A.D.

Drawn beads. Drawn beads[a] (beads prepared from tubes of 2 to 5 mm in length, drawn out from molten glass containing an air-filled cavity) have been found in large numbers on the shores in certain parts of Eastern Africa. These glass beads, discovered at the Kolhapur site, have been dated to be of as early as the first century B.C. to 4th century A.D. and prepared in India. Thin tubes of glass of appropriate length turning out cylindrical beads while still hot and soft were rounded at their edges to give them shapes of an ellipsoid or an oblate. Shiploads of such beads were brought by the Portuguese from India for barter to East Africa in those days, as the historical record shows (Fig. 13).

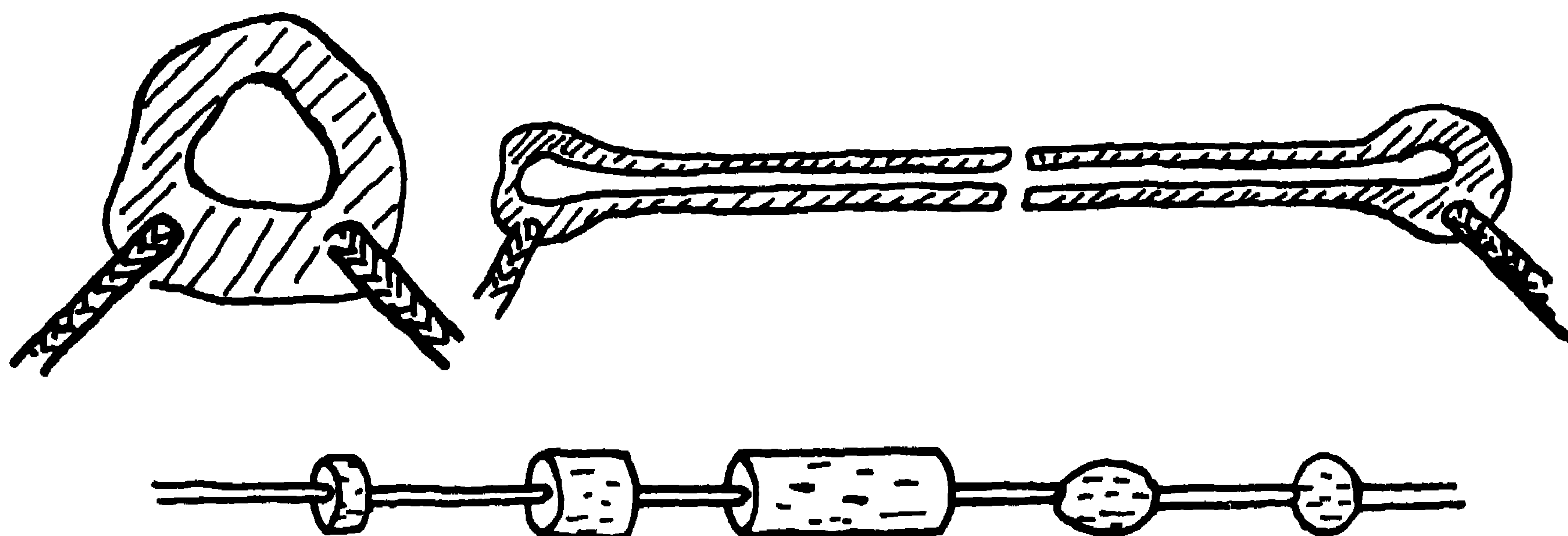


Fig. 13—Drawn beads.

Twisted bead. In making small twisted beads it was common to take a small lump of molten glass on a thin wire and to rotate it briskly till it acquired the desired shape.[b] In most cases annular or spherical beads were made in this manner and are known from the Sātavāhana sites in the Deccan.

Cane-glass bead. A large number of beads from the Sātavāhana sites in the Deccan indicate that they were made from cane[c] glass. In making these, long threads were pulled out and bundled together in a requisite shape. At the time of finishing, these beads (generally cylinder circular in shape) were subjected to a heat treatment so as to produce a uniformly even surface. This process was probably also followed in the gold-foil beads. The upper side of the foil is made up of molten glass when the bundles are rolled on the binding material. In certain cases the glass-maker leaves the surface quite uneven as found in numerous beads from Arikamedu. The use of long canes is

[a] Van Der Sleen, 211–12. [b] Dikshit (5), Bead No. 208.
[c] Dikshit (5), Beads Nos. 201 and 202.

very common in the glass from Arikamedu; specimens recovered from Nevasa,[a] (Fig. 14) Kolhapur, Ter, Tripuri, etc. also show similar characteristics. At Prakash[b] the beads seem to have been made either by spirally winding or by drawing canes or by the simple drawing of viscous matter on the tip of the instrument. Besides, the use of the distinctive technique of perforating these by a poker, which produces a burred edge on one side, is also evident on some beads.



Fig. 14—Beads—cane glass at Nevasa.

Folded bead.[c] Folded beads were made from flattened rods of glass, folded round a wire in the same way as wound beads. In the glass bead of the Sātavāhana period the practice of folding a strip of glass on a spoke and shaping it by rotating seem to have been followed. On disintegration of the glass the fold shows itself

[a] Sankalia *et al.*, 369. [b] Thapar (2), 109. [c] Van Der Sleen, 205.

at the joints. This method appears to have been followed in the beads from Kolhapur as well as Kondapur. At Kolhapur,[a] folded beads seem to have been made by bending a flat strip of variegated glass into the required shape. At Kondapur,[b] a beautiful cylindrical gadrooned bead with collars at the end seems to have been prepared by the folded method. It is made from a bluish green glass. The colour shows a deeper shade in the notches of the gadroons. This suggests that two pieces of folded glass of somewhat different shades of colours were used in preparing this bead. Such practice has, however, been found to be very limited (Fig. 15).

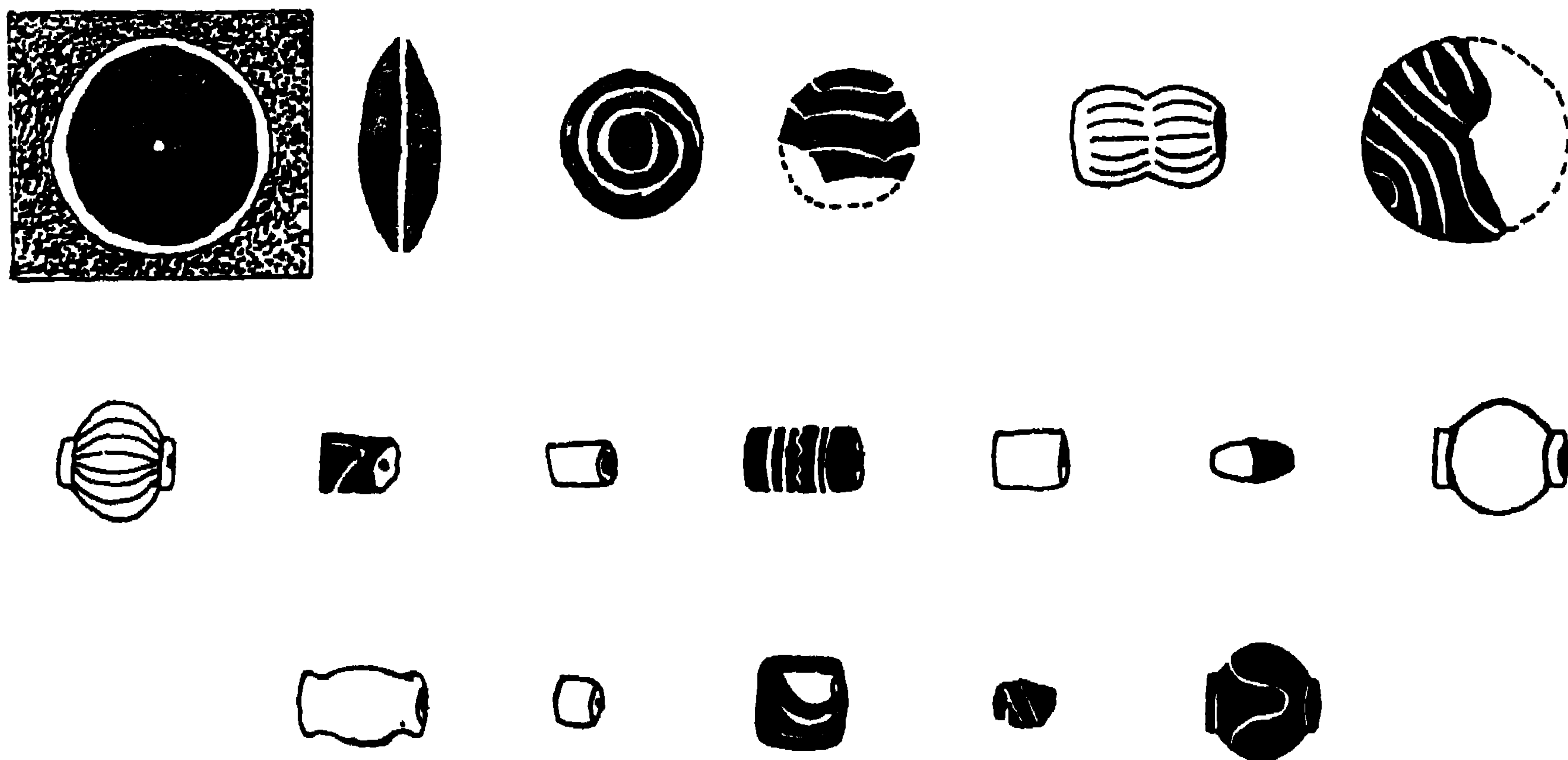


Fig. 15—Folded beads.

Double-strip method.[c] In this case two pieces of molten glass are pressed against each other with a small rod in between them and cut off to the required shape of the bead. The glass used for this bead is free from air bubbles as also from any foreign bodies visible to the naked eye. Such beads have been found at Kondapur.

Pressed bead. Using half-molten glass under pressure, beads of all shapes like hexagonal or square, even bicone or barrel with flattened end can easily be prepared[d] (Fig. 16).

Beads made on the spoke, or hand-perforated glass bead. Several beads of the Sātavāhana period appear to have been made on a comparatively thick spoke. In this case small masses of semi-molten glass are dropped on an earthen platter and then pierced with a pointed spoke, lifting the whole mass from the platter. In this process the bead shows a blurred edge.

Eye-bead. Besides the occurrence of this type of beads in the lands around the Mediterranean, the 'eye-beads' are very widely distributed at Taxila,[e] especially at the Bhir Mound. They were also found at a few other sites like Sravasti, Rajghat, etc.

In making such beads layers of different glasses were overlaid on a matrix

[a] Sankalia and Dikshit, 103. [b] Dikshit (5), Bead No. 205.
[c] Dikshit (5), Beads Nos. 206–209; Van Der Sleen, 207.
[d] Van Der Sleen, 207. [e] Beck (4), 23–24.

resembling the shape of an eye. These are cleverly manipulated to form the design of an eye surrounded by marginal rings in white. There are two main tendencies in the decoration. In one the eyes are distinctly separated from one another and appear as patches on the surface. In the other the eyes and the marginal ring or rings of



Fig. 16—Pressed beads from Taxila: these specimens represent inverted flower pendant, spiral bead, hexagon barrel, ball pendant, flattened drop pendant, folded bead, pyramid pendant, broken ball pendant and several other varieties.

different colours are arranged in a group of two or four and are so spread on the bead surface that the inner matrix of the bead is scarcely seen. Both these types are known among the Indian specimens.[a]

Gold-foil bead. A layer of gold foil is pressed on a glass matrix when hot and is laid over again with another coating of transparent glass. As the foil is not a good cementing article, the material does not form a homogeneous mass and the tendency of the bead is to break at the foil layer.[b]

Most of the beads are generally large spherical or standard barrel in shape and have a collar-like effect at the edges where the two parts of the bead are separated by notches of cylindrical shapes. Beads with gold foil have a very wide distribution in India. In Northern India they are found at Bhita, Patna, Mason Dih, Kausambi, Ujjain, and Tripuri. At Kausambi seven specimens are dated 300 B.C. to the second century A.D., which seem to be stratigraphically the oldest of this type of specimens. In South India beads inlaid with gold foil are found in the Sātavāhana strata at Nasik, Kolhapur,[c] Kondapur, Chandravalli, Karad, Arikamedu, Nevasa,[d] etc.

Red beads with dark brown core. Several beads at Nevasa show a dark brown core and coating of Indian red glass. The three interesting red-coloured beads with a dark brown core were found at Kondapur.[e] These were possibly made by turning a white tubular matrix of white opaque glass around a wire and by applying a thick coating of translucent ruby glass over this matrix. One peculiar bead known as blotched bead[f] was found to consist of a yellow matrix covered over with a coating of green glass.

Millefiori beads. The Italian term *millefiori* (thousand flowers) refers to the method of decorating glass with flowery designs. Composite canes of coloured glass rods were cut across for revealing a design (mosaic glass). Pieces of such canes could be arranged side by side to produce repetitive patterns. Production of beads with such a decorative design was very common in Alexandria in the first century B.C. In Ahicchatra,[g] a small barrel lenticular bead with lug collars having a millefiori pattern on it has been unearthed. It is a folded bead having a blue core and the decoration consists of several vertical hatchings in red, white and black in a double black border. The pattern is laid slantingly across the body of the bead. Another example of a glass article with such a design was found at a site named Rattapinda, a mound not far off from Taxila, but its date is not definitely known. It is a bowl, decorated with several flowers of different colours, with a cellular structure surrounded by black points. The millefiori technique was widely spread over Rome and was highly developed in Venice.

Composite beads. The technique of preparing composite glass of good quality appears for the first time in the Mauryan period. It was a difficult process where two glasses required the same co-efficient of expansion and thus marks a definite advance in the making of glass. A typical bead of blue square-shaped cylinder with white oblique strokes shows a wide distribution in the Deccan in the Sātavāhana layer and in the Gangetic valley during the first and second century A.D. Another peculiar

[a] Dikshit (7), 99. [b] Lal (Dr) (1), 57–58; Sankalia *et al.*, 355.
[c] Sankalia and Dikshit, 101. [d] Sankalia *et al.*, 355. [e] Dikshit (5), Bead No. 212.
[f] Sankalia and Deo, 89. [g] Dikshit (4), 56.

type of bead consists of a white porcelainous matrix overlaid with a brilliant ruby-red glass. Specimens of this category of beads have been found in Kondapur, Kolhapur, Kanheri, Ter and also Ahicchatra.[a] At Kolhapur deep blue glass beads with a white core have been recovered from the late Sātavāhana layers. Nevasa[b] has also yielded light beads of green glass with a yellow matrix in the same layers.

Among the beads collected at Ahicchatra,[c] there are six samples in which a composite has been used. This is done by two processes: (1) by adding an intermediate layer of white glass in between two strips of black (occasionally blue or violet) glass and by moulding them into the requisite shape, and (2) by twisting a number of canes of coloured glass into the requisite shape with an alternating band or bands of white introduced into the spirals at the time of finishing. In the first process, the white band, which is homogeneous with the coloured glass, assumes the shape of an intervening layer, and if the coloured glass is sufficiently transparent, the layer can be seen as if in an oblique cut well below the latter. In the second process the canes of white glass appear in the core in the form of an encrustation of appliqué work. Due to different coefficients of expansion this glass is liable to flake off and leave a small depression or groove on the core. At Kondapur[d] a long strip of plastic glass was wound over a cylindrical tube and its two ends were fused. It was then segmented and the gadroons were cut over the body of each bead. It was then cut off from the segments with a sharp instrument.

BANGLES

Fragments of varieties of bangles, plain and with numerous designs, have been unearthed from different archaeological sites. In some cases, they have been discovered from the very lowest strata of the site (*c.* 400 B.C.–1700 A.D.). It is therefore unlikely that they were imported from a foreign country.

As regards the process of making these bangles no definite idea can however be given. But as specimens of similar bangles are also found in India in the eighteenth century, they are also possibly prepared by a process then in vogue and as described by Dobbs.[e]

Plain bangle. For preparing plain bangles, a few big blocks of crude glass are laid on the floor of the furnace almost in contact with the fire. After being heated for a few minutes they are thrown into a basin of cold water, when they break up into small pieces. These are then transferred into crucibles containing half-molten glass along with colouring matter as may be required. When thoroughly fused the mass is transferred into a second crucible for complete melting. The workman then dips the end of an iron hook (*ankuri*) into the molten glass and takes out a small ball of glass enough for one bangle. This he winds up on the end of an iron spit (*sallakh*) into a thick irregular ring. He then takes up a dagger-shaped tool (*mala*), and resting the end of the iron spit, around which the glass ring is wound up, on a stone slab (*patri*) squeezes the ring with the help of the dagger-shaped tool till it is partially cooled. The ring is then detached from the spit by means of an iron wire (*barhora*) to which it

[a] Dikshit (4), 57. [b] Sankalia *et al.*, 369. [c] Dikshit (4), 60.
[d] Dikshit (5), Bead No. 196. [e] Dobbs, 36–37.

is then removed. From the end of the iron wire it is transferred to the tip of a tapering clay cone (*kalbut*). The workman then holds the clay cone towards the opening of the furnace, pressing the thin handle of the iron wire between his open palm and the surface of the stone slab in such a way that the clay cone is slanted upwards towards the furnace. In his other hand he holds the iron wire which is inserted between the clay cone and the glass ring. Next, by rubbing his open palm against the handle beneath it backwards and forwards over the stone slab he causes the clay cone to spin rapidly round, and the glass ring upon its tip becomes gradually enlarged and slips down to the broad base of the cone until it has grown to the size of a bangle. It is then slipped off and thrown to cool into the pit between the stone slab and the furnace. In specimens from Shahjahanpur and Budaun the glass ring is transferred from the iron spit of uniform thickness (*sallakh*) to the tapering iron spike (*tokla*) and from that to the clay cone. The use of this additional tool is said to produce more evenly shaped bangles. One skilled workman at the big centres of the trade can turn out one thousand plain bangles in one day, working for nine hours. At the smaller factories the average daily outturn of a workman is only five hundred a day. Native glass is used everywhere except in Aligarh and Saharanpur, where certain transparent twisted bangles are made of foreign glass.

In ancient India the bangles or their fragments discovered from the different archaeological sites are both monochrome and polychrome types. The former is more abundant than the latter. The glass, used for these bangles, is generally translucent; in some cases, however, it is opaque and brittle. The workers of the monochrome glass bangles had used a limited range of coloured glass and also a limited range of decoration.

Monochrome bangles. Specimens of these bangles from Maheswar and Navdatoli[a] show that they are translucent and contain streaks of air bubble. Most of the pieces are yellow and black. The black specimens also show fine streaks of red glass within them, which might have been fused with black glass in the form of a thin red plastic glass thread. The shapes of the specimens are monotonous in character, with mainly two types of decorations like incised dots and slanting or vertical short lines, mostly in an irregular manner (Fig. 17). These were possibly engraved when the glass was in a plastic state. This might have been done by revolving the bangle around some rouletting mechanism. Bangles with triangular sections show dot-decoration and bangles with plano-convex sections have linear decorations. The thickness of the bangle (3 mm to 6 mm in diameter) determines the nature of the decoration. The normal thickness was about 2.5 mm, though a few were found with a thickness of 5 mm. At Brahmapuri (Kohlapur),[b] the simplest monochrome bangle is made by putting out a wire from molten glass kept around the furnace in small crucibles.

Polychrome or multicoloured bangles. Complicated types of bangles with multicoloured designs and decorations, unearthed from different excavated areas, indicate the craftsmanship of ancient glass-workers. Bangles from Maheswar and Navdatoli[c] show a varied range of combinations of colour designs. In some bangles of Maheswar

[a] Sankalia *et al.*, 216. [b] Sankalia and Dikshit, 151. [c] Sankalia *et al.*, 217.

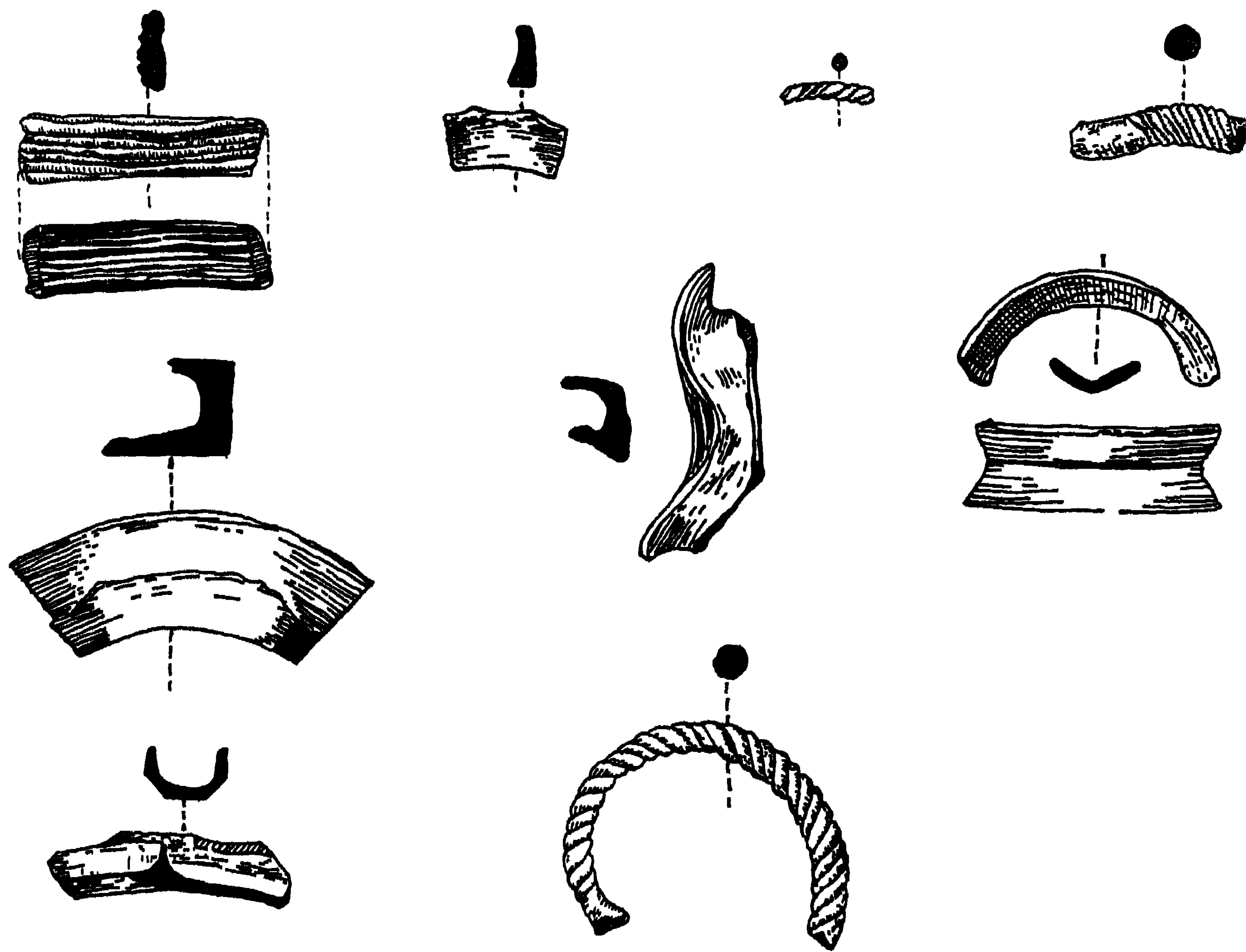


Fig. 17—Monochrome glass bangles.

and Navdatoli wires of plastic glass were possibly placed one above the other and subsequently fused to show vertical bands of various colours. In some cases, wires of differently coloured plastic glass were possibly twisted to give rise to a spiral pattern. In some others, small lumps of colourless plastic glass were possibly laid over the surface of a differently coloured bangle, revealing a design of eyes or dots. In the case of a bangle at Brahmapuri,[a] it was found that possibly two or three thin wires of differently coloured glass were so placed on a thick white band of colourless glass, and then polished off to give a smooth surface, that it might look like a painting over a white background. Some bangles of Nevasa[b] show a skilful combination of wires of differently coloured glass arranged one above the other and then fused together. In some other cases differently coloured glasses were fixed and fused to the body of a broad bangle surface so as to present an ornamental design. One specimen of a polychrome bangle of opaque glass from Bellary[c] shows that after moulding the body part of the bangle, a pattern was produced by applying a lemon-yellow glaze to its surface. The band of lemon-yellow glaze is lighter than the cobalt-blue glass of the body. Another specimen is a moulded fragment of a polychrome bangle of opaque differently coloured glass bands carefully twisted to produce a desired pattern. The upper surface of the bangle shows a white glaze.

[a] Sankalia and Dikshit, 151. [b] Sankalia *et al.*, 447. [c] Lal (Dr) (2), 48–58.

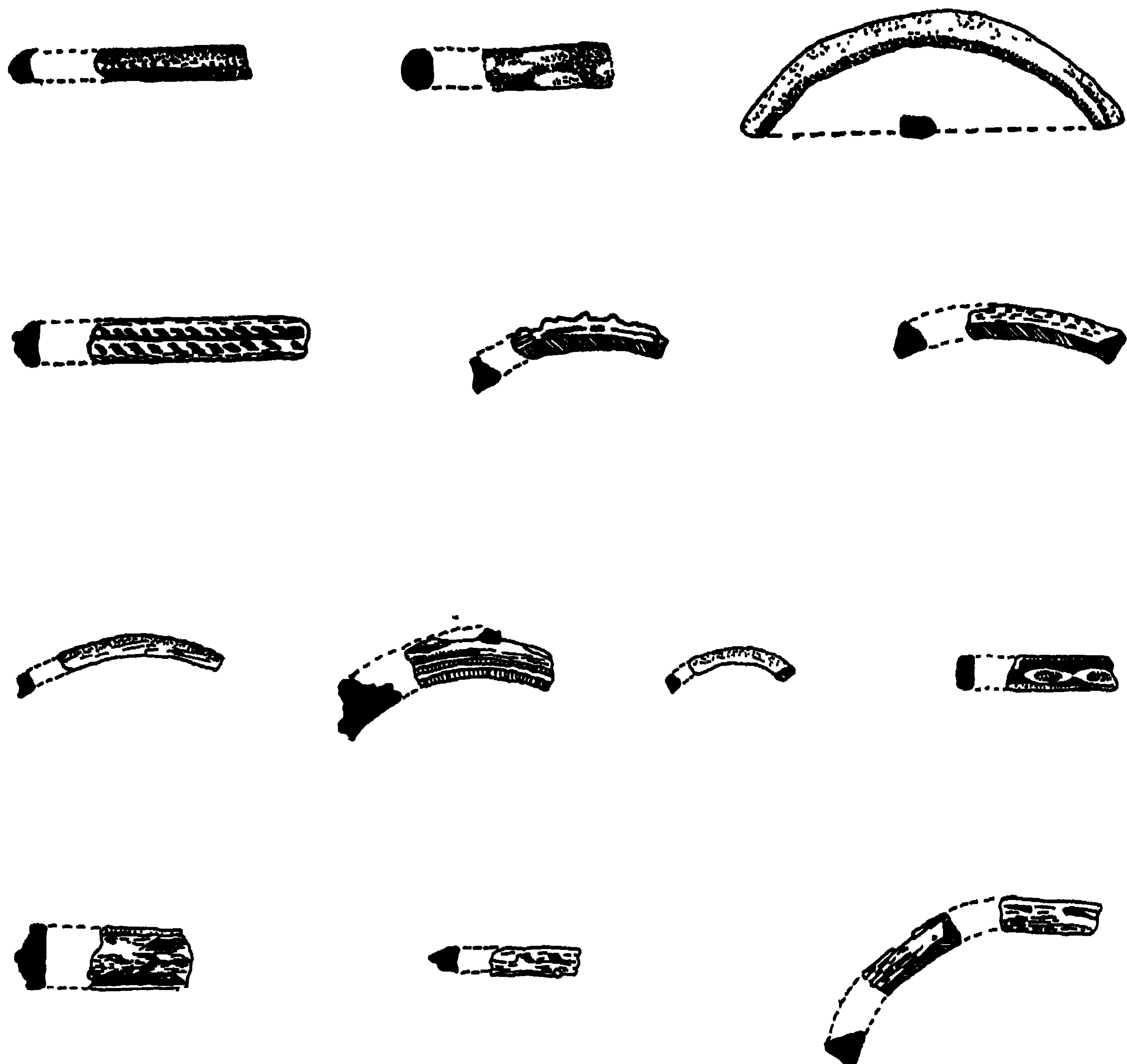


Fig. 18—Polychrome bangles.

FLASKS, BOTTLES AND BOWLS

Besides the varieties of beads and bangles, there are certain rare instances of discovery of flasks, bottles and bowls from a number of excavated areas. Only in a very few cases are these specimens intact, and they are believed to be of foreign origin. There is no doubt that from remote antiquity India had good trade connections with the outside world through land and sea routes. The important cities, towns and coastal ports were the centres of export and import (vide Chapter V). Taxila, one such important trade centre of the early historical period, has yielded three complete unbroken flasks and the upper portion of a glass bottle belonging to Śaka-Parthian levels (Fig. 19). It is assumed that they were made in the Mediterranean country. Here we are not concerned with the place of their origin but only with the the technique of their preparation, as revealed from their outward shape and designs. These vessels of sea-green and jade-green colour[a] have a gourd-shaped tapering body with a flattish base due to blowing and their rims are fashioned by tooling. Their

[a] Marshall (3), 2, 685.

tall cylindrical neck has a small groove at the base. This was possibly made during its cooling. The bases have *pontil* marks and the suspected Brāhmī letter in one case perhaps stands for the initial of the owner of the vessel.

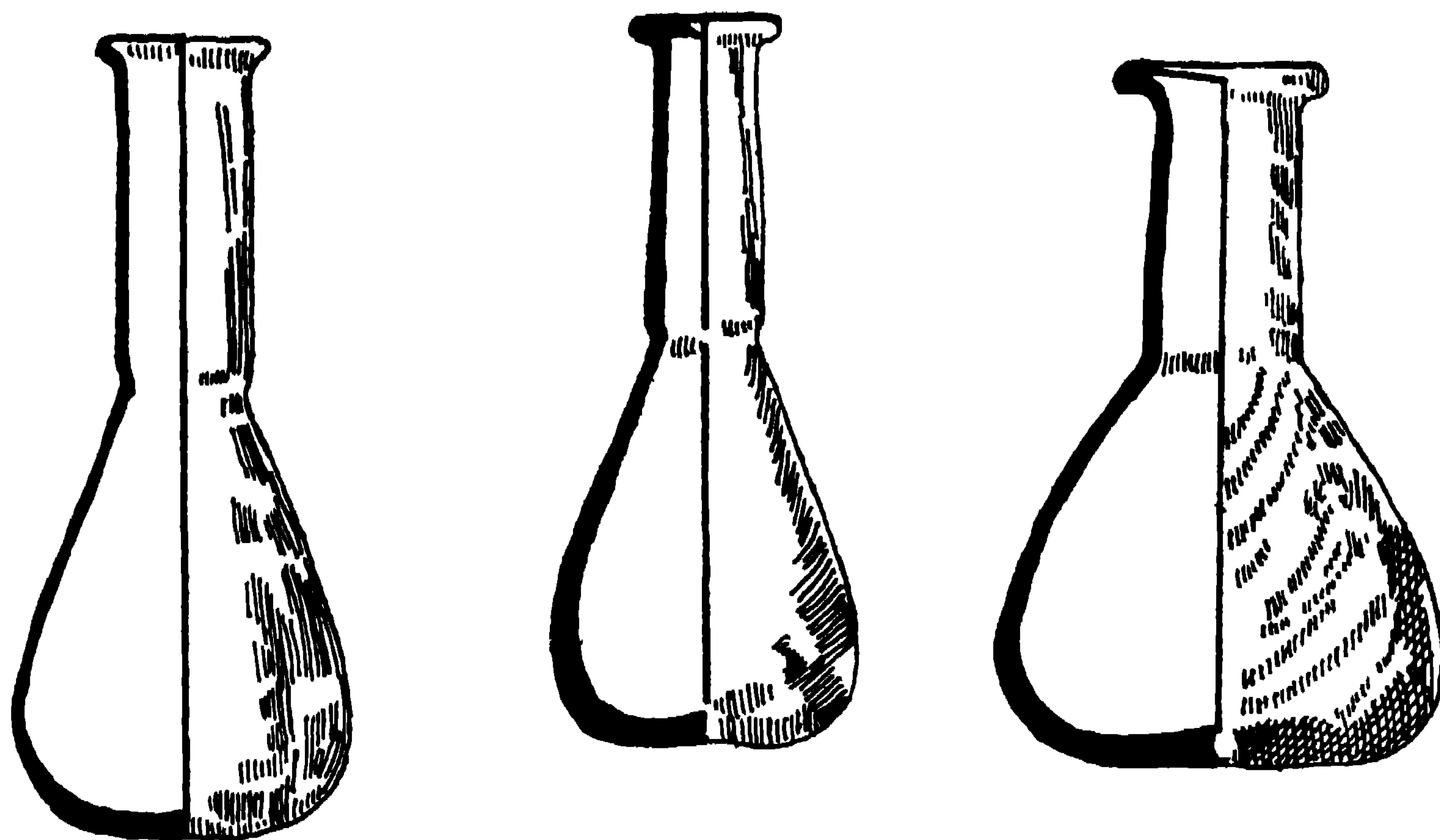


Fig. 19—Flasks from Taxila.

Besides these three complete specimens of glass flasks, Sir John Marshall has grouped a number of foreign glass objects from Taxila under the following heads: (a) lace glass or *vitro di trina*, (b) ribbed ware, (c) swirled glass, (d) blue and white cameo glass, (e) mosaic glass and millefiori glass. Two pieces of the first type,[a] recovered from Sirkap, are the rims of a platter or bowl belonging to approximately the first century B.C. and the first century A.D. respectively. The earlier dated specimen (first century B.C.) seems to have been prepared by taking threads of white and colourless glass twisted into a spiral; the cable was pressed inside a mould probably by coiling and then heated for coagulation into a solid mass. The later one is prepared from canes of blue and white glass alternated with cables of black and white. Two examples of ribbed ware have been recovered from the Śaka-Parthian levels at Taxila. Ribbed ware is made in imitation of metal repousse and from the moulds designed for the purpose. The mouldings appear in high relief over the flush surface of the glass, which generally takes the shape of 'pillars' and hence the glass is often called 'pillar-moulded.'

Ter[b] (Tagara according to Periplus and Ptolemy), another trading port of the first century A.D., has also yielded a flask of agate glass (*c.* 150–200 A.D.), which is said to be of Mediterranean origin. It is conical in shape with a slight omphalos at the base, with a high cylindrical neck and a slightly projecting rim which is damaged. Its rim seems to have been tooled when the batch was being cooled. It is about 7 cm in height and about 5 cm wide at the base. The neck is about 2.5 cm high. The walls are about 3 mm thick all over, somewhat thicker at the base. From the technique it

[a] Marshall (3), 2, 688–89. [b] *IAR* (1967–68), 35.

is clear that it was intended to imitate banded agate, a practice which was very popular in the early centuries of the Christian era.

Arikamedu[a] (near Pondicherry), an Indo-Roman trading station on the east coast of India, has also supplied the evidence of two fragmentary glass bowls belonging to the first century B.C. and the first century A.D., which are said to have been imported to that site. Of these, one fragment consists of a pillar-moulded bowl of whitish iridescent glass and the other of ribbed horizontal bluish green glass, full of bubbles characteristic of Roman glass.

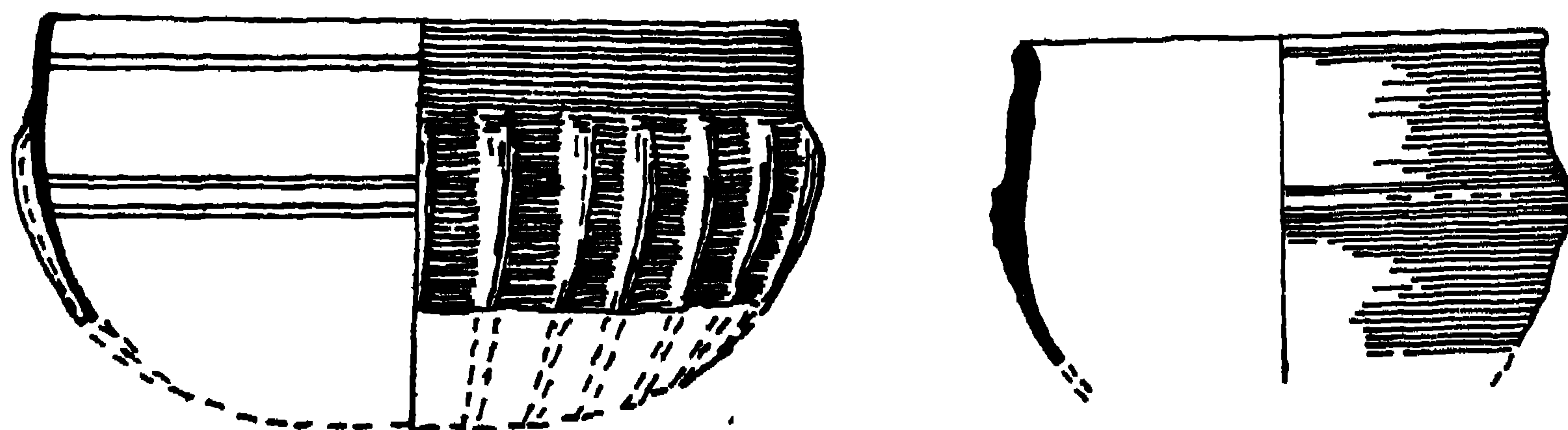


Fig. 20—Fragementary glass bowls.

It is interesting to mention here an example of a complete glass bowl (*c.* 400 A.D.) which was discovered by Cousens in his excavations in 1908–9 at Brahmanabad in Sind (Fig. 21).[b] The bowl appears to have been blown in a mould and is not free from air bubbles. It has a globular belly with vertical ribbings all over the body and a short neck having an out-turned rim. It was covered with an iridescent patina when recovered, which has now peeled off. The thin walls of the bowl appear to be highly transparent having a pale greenish blue tinge. It is now preserved in the Prince of Wales Museum.

A small cut-ware bottle with a high cylindrical neck and cubical body (1.4″ high and about 1″ in diameter), recovered at Karwan (36 miles south of Baroda) appears to have been blown in a mould. According to Goetz,[c] this bottle is of Egyptian origin and is attributed to the eleventh century A.D. (Fatimid period). It was used as an article of trade with India.

The recent discovery (in June 1965) of eight green and greenish blue glass flasks along with thirteen Chinese porcelainous bowls at Baluchipura ward of the old Ahmednagar[d] city in Maharashtra state is another interesting landmark in the history of glass technology (Fig. 22). As the date of these Chinese bowls has been ascertained by the inscriptions of the Ming period their associated glass flasks also belong to the same period (1590 A.D.). This is further supported by the Chinese account of a good trade connection between China and India during this period. The flasks are flattened on the sides with a semi-circular or round body and a tall cylindrical neck, which shows that they were blown and the rims were tooled to form a cavity inside the neck. Impurities like seeds and specks of sand are found to adhere to the body part of

[a] Wheeler, Ghosh and Krishna Deva, 17–124. [b] *ASI/AR* (1908–9), 82.
[c] Goetz, 33–36. [d] Dikshit (9), 74.

these flasks and a whitish film is visible on their surface due to devitrification. A sticky blackish residual substance in the flasks indicates that they were possibly used as wine-flasks.

Glass specimens of the Mughal period preserved in the different museums of the world clearly show the Persian influence in art and design. It was during the

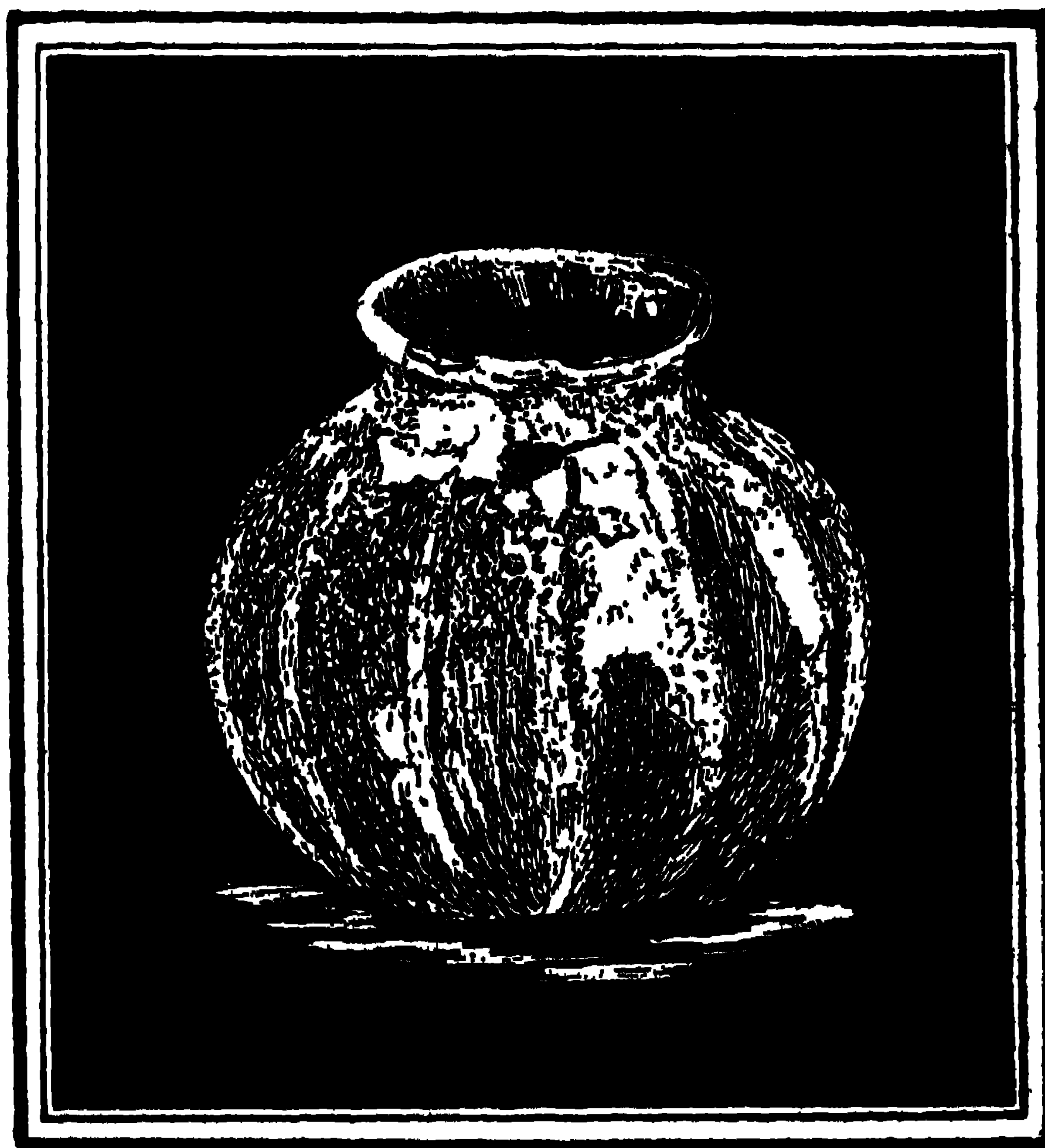


Fig. 21—A complete glass bowl from Brahmanabad.

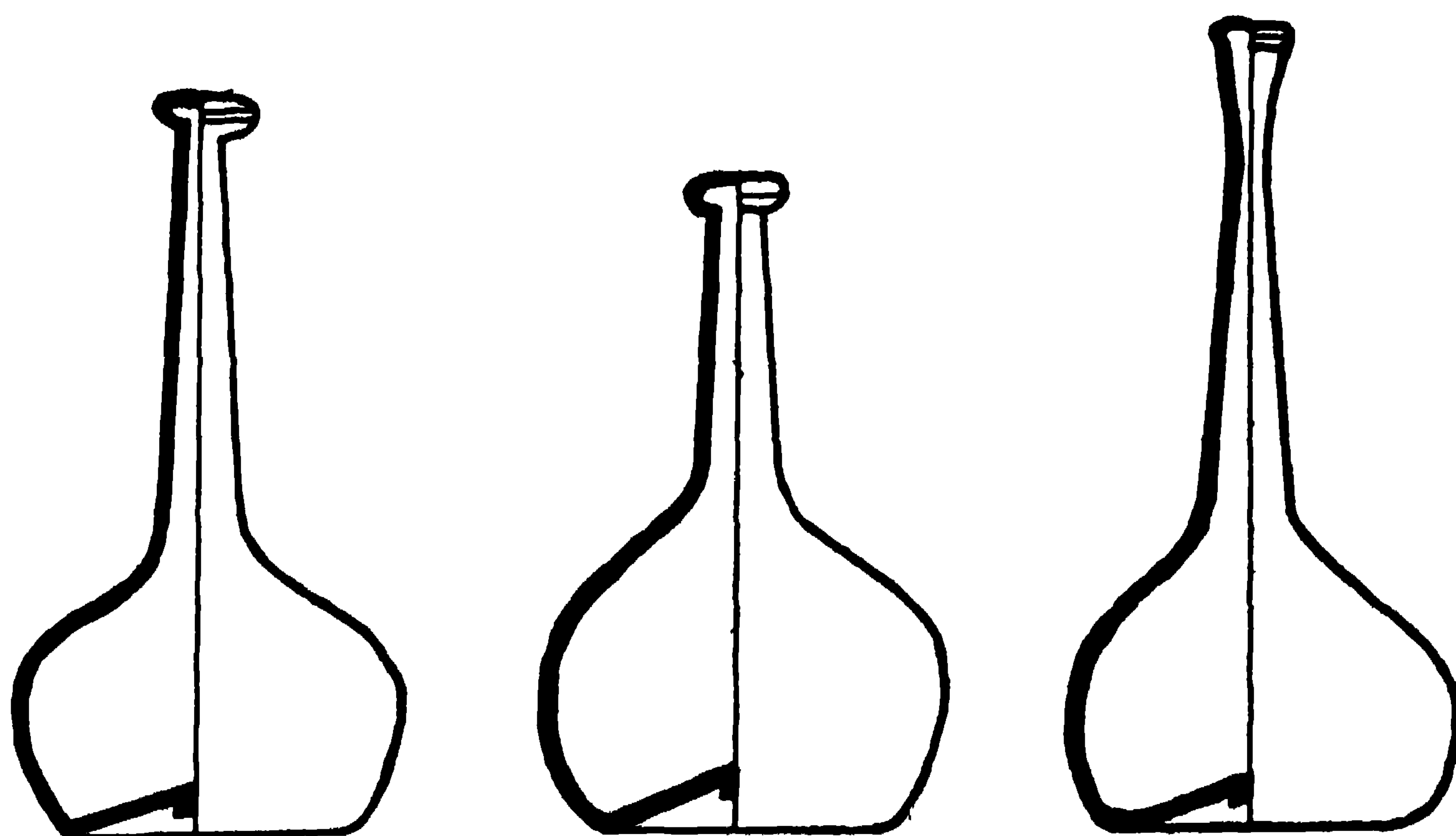


Fig. 22—Glass flasks from Baluchipura.

Mughal rule that many Persian craftsmen came to India and played an important role in the manufacture of glass articles by introducing new designs and adding a new delicacy. Thus it ushered in a new era in the history of glass technology. Some of these specimens were imported into the Indian market for trading purpose. The specimens of the Mughal period may be grouped into following categories: (a) hukkah bowls of various shapes—chambu-shaped, flat-bottomed and free-standing, etc.; (b) dishes and dish covers; (c) spittoons; (d) mirrors; (e) spectacles and (f) other miscellaneous objects. A vivid description of these specimens,[a] giving their size, colour etc. along with the names of the Museums where they are now preserved is given in Table XXXII.

Most of the Mughal specimens, as far as could be judged from an examination of their appearance, were possibly made by the blowing process; but the glass was not of good quality, being full of air bubbles and seeds. Specimens of Mughal glass of the later period are found to be more characteristically opaque than the earlier ones. In the earlier Mughal specimens of blue-coloured glass, copper was preferably used as colouring agent, while cobalt was widely used for this purpose in the later specimens. Green and gold seem to be the most favourite combination. Bright opaque lemon-yellow glasses are abundant among the later Mughal specimens and the process of gilding seems to have been very common in this period.

Some Dutch and English specimens[b] have also been included in Table XXXII. They are characterized by distinctive Indian designs and were freely imported into the Indian market. Some of these were gilded and enamelled.

Other miscellaneous objects like seals, tiles, ear-reels have also been recovered from various excavated sites. The impression on a glass seal (4th century B.C.), as in the case of a black tablet with a symbol of an elephant on it found at Maheswar,[c] was made while the tablet was still hot and in a semi-molten state, so that it has left slightly raised borders on the two sides. The impression was perhaps made with a punch-marked or cast copper coin bearing the symbol of an elephant (Fig. 23).

TILES

A floor of glass tiles, recovered from Dharmarajika Stupa from excavations at Taxila,[d] and made possibly during the reign of Asoka, was found to consist of bright azure blue, black, white and yellow tiles. These tiles are transparent and measure 10¼″ square and ⅛″ in thickness. The production of such large objects requires a good knowledge of moulding and annealing to remove the internal strain. These tiles are still in a good state of preservation and are free from fracture and devitrification. This provides evidence of a high order of technical skill in their production.

Glazed earthen ware tiles are abundantly found in many mosques and palaces of the Mughal period.[e] The composition of glazes, as is well known, corresponds to that of glass. These glazes are also often coloured with the addition of various colouring agents.

Much of the information regarding the tools and implements and the processes

[a] Dikshit (9), 82–104. [b] Dikshit (9), 104–12 [c] Sankalia (2), 197–204.
[d] Marshall (2), 59. [e] Yazdani, 44–49.

and techniques employed for making beads, bangles, bowls and other miscellaneous objects in ancient and medieval India, as described in the previous pages, was collected from the local workers of the present day at the different sites of excavation.



Fig. 23—A glass seal with elephant symbol.

They, it may be assumed, do not differ to any notable extent from those used in early days, because, as is well known, the crafts and professions in ancient India were made hereditary by the code of Manu and other lawgivers.

TABLE XXXII

Mughal, Dutch and English Glasses

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Bottles	A small bottle—with a small base, a globular body, a tall cylindrical neck, a short projecting rim, a domical cover with a bud shaped tapering knot ending in a point.	*Victoria and Albert Museum*, Bombay. (No. I.M. 11354)
Hukkah Bowls		
Three types: A. Chambu-shaped B. Flat based C. Handy hubble-bubbles These are again sub-divided according to their design and decoration.	A. *Chambu-shaped*—base with a spherical body. A (i). Gilding on the body fabric of the bowl. About 18.5 cm high, a very large bulbous body, a short funnelled mouth; width 18 cm. Greenish blown glass. *c.* 1700 A.D., Mughal.	*Victoria and Albert Museum*, London. (No. I.M. 15–1930)
	Blue Chambu-shaped bowl. 1700 A D.	*Cleveland Museum*, Ohio. (No 61.44)
	A (ii). Bowls decorated with cut-to-shape pieces of glass. Green foiled Chambu-shaped bowl—globular body with a high cylindrical neck. Height: 17 5 cm Width: 18 cm Mughal, late 17th century.	*Victoria and Albert Museum*, London. (No. I.M. 109–1923)
	Chambu-shaped bowl—the shoulders show wheel-cut ovoid drops. Height: 17 cm. Width: 16 8 cm. *c.* 1700 A.D.	*Victoria and Albert Museum*, London. (No. I S. 90–1948)
	Chambu-shaped bowl (with clear and transparent glass). Height: 17 cm. Width: 17.5 cm. *c.* 1700 A.D.	*Salar Jung Museum*, Hyderabad. (No. SJM 123)

(contd.)

TABLE XXXII (*contd.*)

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Hukkah Bowls (contd.)	Chambu-shaped bowl (clear and transparent glass with occasional striae). Early 18th century A.D. (possibly English).	*National Museum of India*, New Delhi. (No. 8:67)
	Chambu-shaped hukkah with a heavy appearance by gilding. Height: 18 cm. Width: 7 cm. *c.* 1750 A.D. (probably Persian).	*Salar Jung Museum*, Hyderabad. (No. SJM 121)
	A tall bottle, belonging to the above-mentioned type, with a heavy gilding. Height: 27 cm. Width: 10 cm. Height of neck: 12.5 cm. *c.* 1750 A.D. Persian or made in Persian style in India.	*Salar Jung Museum*, Hyderabad. (No. 162)
	A (iii). Chambu-shaped bowl with wheel-cut decoration. The vessel is made of clear transparent glass with its globular surface. Height: 16 cm. Width: 16 cm.	*Salar Jung Museum*, Hyderabad. (No. SJM 146)
	Hukkah bowl with partitioned globular surface (bubble-free glass). Height: 16.5 cm. Width: 16 cm. Early 18th century A.D.	*Salar Jung Museum*, Hyderabad. (No. SJM 119)
	Chambu-shaped hukkah bowl with wheel-cut decoration (clear, transparent and thick walled glass). Height: 16 cm. Width: 14 cm. Mughal, probably belonging to the period of Jahangir. Delhi work.	*Salar Jung Museum*, Hyderabad. (No. SJM 117)

(*contd.*)

TABLE XXXII (*contd.*)

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Hukkah Bowls (contd.)	Chambu-shaped bowl. Height: 18 cm. Width: 16.5 cm. Mughal.	*Salar Jung Museum*, Hyderabad. (No. SJM 127)
	Chambu vessel of clear glass.	*National Museum of India*, New Delhi. (No. 23: 67)
	Chambu bowl of clear transparent blown glass with thick walls and a few air bubbles. Height: 18 cm. Width: 15.5 cm. Middle of 18th century A.D.	*Prince of Wales Museum*, Bombay.
	Hukkah bowl with slight greenish tinge. Height: 16.5 cm. Width: 15.5 cm. Mughal.	*Salar Jung Museum*, Hyderabad. (No. SJM 122)
	Chambu-shaped hukkah bowl with clear and blown glass. Height: 17 cm. Width: 17.5 cm. Late Mughal.	*Salar Jung Museum*, Hyderabad. (No. SJM 123)
	Chambu-shaped bowl. Height: 17 cm. Width: 16.5 cm.	*National Museum of India*, New Delhi. (No. 17.67)
	Hukkah bowl (Chambu-shaped) of clear transparent glass, blown and trailed with a grip near the neck. Height: 16.5 cm. Width: 15.5 cm. Mid-Eighteenth century A.D., probably made in Delhi.	*Prince of Wales Museum*, Bombay. (No. 58: 11)
	A (iv). Simpler forms of hukkah bowls. Chambu-shaped hukkah bowls with simpler form. During the 19th century.	*Victoria and Albert Museum*, Bombay. (Nos. 149, 151, 153)

(*contd.*)

TABLE XXXII (*contd.*)

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Hukkah Bowls (contd.)	Chambu-shaped bowl. Its neck is pillar moulded and is shaped like a miniature bowl with gadroons and flaring rim. During the 19th century.	*Victoria and Albert Museum*, Bombay. (No. F.F. 257) *Prince of Wales Museum*, Bombay. (No. 58: 54)
	A (v). Hukkah bowls painted in enamel; Chambu-shaped. Height: 17 cm. Width: 18 cm. Early half of 18th century A.D.	*Salar Jung Museum*, Hyderabad. (No. SJM 120)
	Chambu-shaped bowl. Probably made in Venice for the Indian market.	*Salar Jung Museum*, Hyderabad. (No. SJM 125)
	Chambu-shaped bowl of a very fine glass with green tinge.	*Bharat Kala Bhavan*, Benares. (No. BKB 9964)
	B. *Hukkah bowls with flat bases*, i.e. high domed vessel with a short neck.	
	B (i). Hukkah bases of gilt glass. (a) Height: 19 cm. Width: 18 cm. Probably belong to late Mughal or early 19th century A.D.	*Salar Jung Museum*, Hyderabad. (No. SJM 141)
	(b) Hukkah bases of gilt glass. Height: 18 cm. Width: 17 cm.	*Salar Jung Museum*, Hyderabad. (No. SJM 152)
	(c) Height: 17 cm. *c.* 1700 A.D.	*Victoria and Albert Museum*, Bombay. (No. 91: 1948) *National Museum of India*, New Delhi. (No. 30: 67)
	B (ii). Hukkah bases with wheel-cut decorations (three types of specimens).	

(*contd.*)

TABLE XXXII (*contd.*)

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Hukkah Bowls (contd.)	(a) Wheel-cut decoration spread over entire surface (2 in number). 1. Height: 17 cm. Width: 17 cm.	*Salar Jung Museum*, Hyderabad. (No. SJM 131)
	2. Deep amber coloured glass. Height: 17 cm. Width: 16 cm. Possibly made at Kapadwanj in Gujarat (19th century A.D.).	*Salar Jung Museum*, Hyderabad. (No. SJM 135)
	(b) Hukkah base with Buttas appearing singly or as diapers (4 in number).	
	1. Hukkah base, flat bottomed, with meandering border at the base, clear transparent glass full of bubbles. Height: 16.5 cm. Base: 17 cm.	*Salar Jung Museum*, Hyderabad. (No. SJM 118)
	2. Shaped like the pawn. Possibly made in Venice for the Indian market.	*Victoria and Albert Museum*, Bombay. (No. 1.5. 15–1893)
	3. Hukkah bowl of milky white glass with thin border of herring at the base. Possibly made in Venice for the Indian market.	*Victoria and Albert Museum*, Bombay. (No. 77: 256)
	4. Hukkah bowl of clear and transparent glass with free air-bubbles. Height: 18.3 cm. Width. 16.4 cm. *c.* 1700 A.D.	*Prince of Wales Museum*, Bombay. (No. 59: 24)
	(c) Specimens with the motif enclosed in mihrabas or arches (4 in number).	
	1. Hukkah bowl. Height: 17 cm. Width: 16 cm.	*Salar Jung Museum*, Hyderabad. (No. SJM 126)

TABLE XXXII (*contd.*)

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Hukkah Bowls (contd.)	2. Songati shaped clear transparent glass without a flaring broad base. Height: 17 cm. Width: 15 cm.	*Salar Jung Museum*, Hyderabad. (No. SJM 134)
	3. Hukkah bowl of cobalt coloured opaque blue glass. Height: 18.5 cm. Width: 17.4 cm. 18th century A.D.	*Prince of Wales Museum*, Bombay. (No. 58: 10)
	4. Hukkah bowl of same category.	*National Museum of India*, New Delhi. (No. NMD 27: 67).
	(d) Decorative designs in diapers, i.e. carpet-like pattern (4 in number). Mughal. 1. Hukkah bowl. Height: 17.5 cm. Width: 16 cm.	*Salar Jung Museum*, Hyderabad. (No. SJM 148)
	2. Hukkah bowl. Height: 17 cm. Width: 16 cm. Mughal.	*Salar Jung Museum*, Hyderabad. (No. SJM 150)
	3. Hukkah bowl.	*National Museum of India*, New Delhi. (No. NMD 19: 67)
	4. Hukkah bowl of dull opaque white coloured glass. Height: 17.5 cm. Width: 17 cm. Late Mughal.	*Victoria and Albert Museum*, Bombay. (No. 92: 148)
	B (iii). Painted hukkah bowls. Hukkah bowl with torpedo-shaped enclosure. Height: 17 cm. Width: 17 cm. During the reign of Jahangir.	*Salar Jung Museum*, Hyderabad. (No. SJM 132)

(*contd.*)

TABLE XXXII (*contd.*)

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Hukkah Bowls (contd.)	Hukkah bowl with torpedo-shaped enclosure of green colour with its various shades. Thin glass at the walls and extra-ordinarily large air pockets in the body. Height: 17 cm. Width: 17 cm.	*Salar Jung Museum*, Hyderabad. (No. SJM 155)
	A pair of hukkah bowls with identical decorations.	*Salar Jung Museum*, Hyderabad. (Nos. SJM 128 and 129)
	Hukkah bowl of similar decoration. Height: 17 cm. Width: 16 cm. Mughal period.	*Salar Jung Museum*, Hyderabad. (No. SJM 155)
	Hukkah bowl with lotus design. Height: 17 cm. Width: 16.5 cm.	*Salar Jung Museum*, Hyderabad. (No. SJM 154)
	Hukkah bowl with the design of a drooping lily.	*Salar Jung Museum*, Hyderabad. (No. SJM 133)
	Hukkah bowl with similar design.	*Salar Jung Museum*, Hyderabad. (No. SJM 150)
	Hukkah bowl with the design of a Champaka flower.	*Salar Jung Museum*, Hyderabad. (No. SJM 159)
	Three specimens of similar design.	*Salar Jung Museum*, Hyderabad. (Nos. SJM 128, 129 and 155)
	Squat Hukkah bowls: Intermediate between the Chambu-shaped bowl and the flat based hukkah (6 in number). Probably made in Patna or Murshidabad during the Mughal period.	

(*contd.*)

TABLE XXXII (*contd.*)

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Hukkah Bowls (contd.)	1. Squat hukkah bowl with Chambu-shaped dome and in inverted saucer base, violet coloured translucent glass. Height: $3\frac{3}{4}''$. Base: $3''$.	*Bharat Kala Bhavan*, Benares. (No. BKB 9108)
	2. Hukkah bowl similar to the previous one (blue translucent glass). Height: $3\frac{1}{2}''$. Base: $3''$.	*Bharat Kala Bhavan*, Benares. (No. BKB 9106)
	3. Similar to No. 1 above (turquoise blue translucent glass with gold work). Height: $4''$. Base: $3\frac{1}{2}''$.	*Bharat Kala Bhavan*, Benares. (No. BKB 9103)
	4. Similar to No. 1 above (turquoise coloured translucent glass). Height: $3\frac{1}{2}''$. Base: $3''$.	*Bharat Kala Bhavan*, Benares. (No. BKB 9107)
	5. Similar to above No. 1 hukkah bowl with a very high saucer based base and a more elliptical dome, light-blue-green transparent glass. Height: $3\frac{1}{2}''$. Base: $3''$.	*Bharat Kala Bhavan*, Benares. (No. BKB 9105)
	6. Similar to No. 1 above. Pale yellow or cream coloured translucent glass. Height: $3\frac{3}{4}''$. Base: $3\frac{1}{4}''$.	*Bharat Kala Bhavan*, Benares. (No. BKB 9104)
	C. *Hukkah bowl with handy hubble-bubbles*: Coconut-shaped handy hubble-bubbles with a tapering bottom and a solid knob at the terminal; mouth cylindrical in shape with a ledge in the middle. It is made from blown glass of dark leafy green colour and is free from bubbles. The glass is transparent.	*Salar Jung Museum*, Hyderabad. (No. SJM 142)

(*contd.*)

Table XXXII (*contd*)

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Hukkah Bowls (contd.)	Chambu-shaped hukkah. Height: 11 cm. Diameter: 10 cm. Possibly of Mughal period.	*Victoria and Albert Museum*, Bombay. (No. 15: 1930).
	Coconut-shaped handy hubble-bubble without any knob at the base. It is made from emerald green glass and appears to have been made from a mould. A short cylindrical tube is attached to the shoulder in a slanting position and a curved handle connects it to the mouth. Late Mughal period, *c.* 1750 A.D. Appears to be non-Indian.	*Salar Jung Museum*, Hyderabad. (No. SJM 140)
Sprinklers (4 in number)	Sprinkler—flat sided container, circular in shape and provided with a splayed pedestal base and a long tapering neck, about 4½″ in height, with a three-pronged rim. Milky-white and opaque glass.	*Bharat Kala Bhavan*, Benares. (No. BKB 9098)
	Tallest sprinkler—about 9″ in height with a small globular body as its receptacle. Its neck is about 7″ high and at the base of the neck there is a smaller bowl with a shark carination.	*Bharat Kala Bhavan*, Benares. (No. BKB 9193)
	Smaller sprinkler—about 5″ in height with a tapering lower bowl, almost gourd-shaped, capped by a small carinated bulge and a long bulging neck about 2″ in height (clear transparent glass).	
	Simpler form of sprinkler with a bulbous body (clear, transparent glass, free from air bubbles). Early Mughal period (1656 A.D.) of Bijapur.	*Victoria and Albert Museum*, London. (No. I.S. 13–1893)

(*contd*)

TABLE XXXII (*contd.*)

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Unguent Jars (3 in number)	Unguent jar with sloping sides, a constricted and funnel shaped neck with a short projecting rim. Height: 2¼″. Width: 1½″ at base and about 1¼″ near neck. Mughal period.	*Bharat Kala Bhavan*, Benares. (No. BKB 9510)
	Large jar (broken at the neck)—about 2½″ in height and about 1¼″ in diameter at the base. Straight walled jar with a sharp dome near the short neck, about ½″ in height; out-turned and thick rim. Mughal period.	*Bharat Kala Bhavan*, Benares. (No. BKB 9583)
	Jar shaped like a miniature handle or a water pot with a rounded flat base, a bulbous body with a sharp carination at the waist, a constricted funnel-shaped neck and out-turned rim, milky-white glass. Mughal period.	*Bharat Kala Bhavan*, Benares. (No. BKB 9193)
Dishes (7 in number)	Platter—about 15 cm in diameter, very short flaring rim; flat except for a small protuberance in the centre; developed by the use of pontil; pale transparent copper-blue glass. Mughal period.	*Victoria and Albert Museum*, Bombay. (No. 1699)
	A pair of dishes with short out-turned rims, nearly 11 cm wide and about 1½ cm in height near the rim. Mughal period.	*National Museum of India*, New Delhi. (Nos. 12 & 16 of 1967)
	Pale blue glass dish of about 7 cm wide. Mughal period.	*National Museum of India*, New Delhi. (No. 14–67)

(*contd.*)

TABLE XXXII (*contd*)

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Dishes (contd.)	Pale transparent bluish glass dish, about 9 cm wide, with a square base and a short rim. Appears to belong to Jahangir's reign. An outstanding example of Mughal Art.	*National Museum of India*, New Delhi. (No. 10–67)
Flower-pot (a rare example)	A long torpedo-shaped body tapering very sharply towards the base; a long funnel-shaped neck, with a ledge in the middle, erected over an inverted cup-shaped pedestal base with a spherical stem. Height: 10″. The shape of the flower-pot is typically Persian. Mughal period, *c.* 1700 A D.	*Bharat Kala Bhavan*, Benares.
Four-sided Bottle	A small four-sided bottle (probably used as an inkpot) of about 2″ height, having a short neck and a rounded rim (yellow translucent glass). Made in Holland probably for Indian market.	*Bharat Kala Bhavan*, Benares. (No. BKB 9195)
Bowl	Tulip-shaped bowl of pale bluish translucent glass (full of bubbles and impurities) having a flaring rim and omphaloid base. Mughal.	*National Museum of India*, New Delhi. (No. 26–27)
Dish-cover	A domical shaped dish-cover with a solid knob at the top, about 20.5 cm in diameter and about 9 cm height. The glass is clear and transparent but full of bubbles and straiae. Probably made in Venice or England. Indian workmanship is noticeable. Of late Mughal period, i.e. *c.* 1750 A.D.	*Prince of Wales Museum*, Bombay. (No. 56: 52).
Spittoons	The top-dish is about 11″ in diameter and is slightly mis-shaped. The lower bulbous bowl of the dish appears to have been made by blowing while the flattish part at the top seems to have been	*Victoria and Albert Museum*, Bombay.

(*contd.*)

TABLE XXXII (*contd.*)

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Spittoons (contd.)	fashioned by hand by the manipulation of the tongs. The glass is clear transparent but full of air-bubbles. Mughal period. Mughal in conception.	
	A medium-sized spittoon (of green emerald glass) with the upper dish measuring about 4″ in diameter and about 3″ in height. Acquired from Baganpalle in the Cudappah district.	Private collection at Hyderabad.
Glass Backs for Hand Mirrors	Mirror backs normally rectangular in shape, about 11 cm × 9 cm, with a triangular tip at the apex and a bar-handle or tri-angular holder at the base. Opaque-green or light mutton-fat coloured glass. Mughal period.	*Salar Jung Museum*, Hyderabad. *Dikshit's collection.* Upper levels of the Paithan Excavations (conducted by the Archaeological Department of the former Hyderabad State), now preserved in the *State Museum* at Hyderabad and in *Bharat Kala Bhavan*, Benares.
	Dutch and English glass	
Dutch Bottles (5 in number)	1. Rose-water bottle. Base: 6.5 cm square. Height: 14 cm. Blue opaque glass, moulded, enamelled and gilt. Pontil marks at the base. Neck embellished with a clasp, chain and stopper with a six-stuiver coin. The first quarter of 18th century A.D. Made in Holland. It was manufactured for the Indian market by Dutch painters. They tried their best to copy Indian patterns, design and even subjects to suit the taste of their Indian customers.	*Victoria and Albert Museum*, London. (No. 14. 67)

(*contd.*)

TABLE XXXII (*contd.*)

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Dutch Bottles (contd.)	2 Rose-water bottle. Base: 7 × 7 cm. Height: 17 cm. Clear transparent glass, moulded, gold-gilt and decorated in enamel paints. Blown glass pontil marks at the base. Neck embellished with silver clasp and stopper with a Dutch six-stuiver coin as on Bottle No. 1.	*Victoria and Albert Museum*, London. (No. 17. 67)
	3. Rose-water bottle. Base: 7 × 7 cm Height: 14 cm. Turquoise blue opaque glass, full of bubbles, gilded and enamelled. Moulded and with pontil marks at the base. Silver stopper and clasp at the neck with the coin missing. It has same decoration on opposite walls (a & c) (b & d).	*Victoria and Albert Museum*, London. (No. 17. 67)
	4. Rose-water bottle. Base: 6.25 × 6.25 cm. Height: 13 cm. Opaque enamelled bright leaf-green glass, gilt. Made from moulds, with pontil marks at the base. Clasp and stopper with a Dutch coin of six stuivers in silver.	*Victoria and Albert Museum*, London. (No. 16. 67)
	5. Rose-water bottle (one of the finest bottles in the series). Base: 6.5 × 6.5 cm square. Height: 14 cm. Turquoise blue opaque glass, gold-gilt and richly enamelled. Moulded with pontil marks at the base. The neck has a silver clasp and a stopper with a Dutch coin of six stuivers. Dated 1730 A.D. Others features are the same.	*Victoria and Albert Museum*, London. (No 15. 67)
English Bottle	Four-sided bottle with domical top, a short neck with flaring rim, gold-gilt and painted. Clear glass with a slight greyish tinge. The mode of decoration is similar to the bottles earlier described. Dated about 1725–30 A.D. or a little later. Possibly of English manufacture and made for the Indian market.	*Corning Museum*, Corning, N Y. (No. 59.1.583)

(*contd.*)

TABLE XXXII (*contd.*)

Varieties of specimens	Shapes and decoration	Name of the Museum where the specimens are deposited
Ink-bottles (2 in number)	Small ink-bottles of transparent blue glass (coloured with cobalt), gilded and enamelled. Their walls are about 4 cm square at the base, about 6.5 cm high and having an open mouth about 3.5 cm wide. Dated about 1750 A D. or a little earlier.	*Salar Jung Museum*, Hyderabad. (Nos. SJM 103-A and 106-A)
Hukkah Bases (2 in number)	Diamond point engraved Chambu-shaped flask with a short vertical neck having a broad ridge in appliqué for the holding. Dated about 1740–1750 A D. Made in England for export to India.	*Corning Museum*, Corning, N.Y. (No. 65.2.14)
	Chambu-shaped bowl embellished with a ring base and engraved with the diamond point. The beginning of 18th century A.D. Probably Venetian origin.	*Salar Jung Museum*, Hyderabad. (No. SJM 147)

CHAPTER V

INDIAN GLASS AS AN ARTICLE OF TRADE

In the foregoing chapters an account of the occurrence of glass and its making in ancient and medieval India has been given. In this chapter Indian glass as a commodity of export and the import of some foreign glass into India will be discussed.

Trade connection between Rome and India was established via the Persian Gulf and the Red Sea during the reign of the Roman Emperor Augustus. Greece and especially Egypt, Syria, Jewish Armenia, Caucasus and other small countries of Asia Minor served as intermediaries. These countries were under the Romans in those days. Arabia and Somaliland, not under the domination of Rome, might also have served as intermediaries, and thus seemed to control the trade between the east and the west. But the Parthians, then the rulers of Iran, acted as a stumbling block on the route between Rome and India.[a]

India's ports on the western coast, as mentioned in the *Periplus* (1st century A.D.), were Babaricon, Barygaza (modern Broach), Suppara (modern Sopara), Calliana (modern Kalyan), Mandagora (modern Bankot), Malizigara (Rajapura), Noura, Tyudis, Muziris, Nelcynda, Balita and Comari whereas her eastern ports were Togara (modern Ter), Masulipatam, Nellore, Sopatma, Poduca (Arikamedu), Camara, Taprobane (Ceylon). The *Periplus* records the import of glass vessels at Barbaricon and of crude glass at Barygaza.[b] It is recorded by Pliny, Warmington and other historians that glass was first produced in Phoenicia and widely used in Egypt where the technique generally developed well.[c] Later the industry flourished in Italy during the first century A.D. Glass articles from all these places are reported to have been exported to India.

That Arikamedu was a flourishing Indo-Roman trading station is clearly established by the recovery of some Roman Arretine pottery, Roman lamps and glass ware at the beginning of the Christian era. According to the *Periplus* it is likely that the maritime trade between the Mediterranean world and western India with a coastwise or overland extension to the Coromandel coast was regularly carried on as early as *c.* 30 A.D. Here the western traders settled under a formal agreement with the Indian rulers, and came into contact with convoys of merchantmen from the high seas. Some of the Roman coin-hoards found in India at places far from the sea bear an indirect testimony to the penetration of the earlier western traders into the interior of southern India. The Arikamedu amphorae no doubt represent this maritime trade.[d] Pillar-moulded bowls originated apparently in Italy and spread throughout the Roman world from the end of the first century A.D. Fragments of four or five such bowls found at Arikamedu have a striking similarity with those discovered at Arika-

[a] Chakraborti, 4. [b] Schoff, 39, 49. [c] Pliny, XXXVI, 65; Warmington, 271.
[d] Wheeler *et al.*, 41.

medu by archaeological excavations. Prof. N. K. Sastri also states that the objects found at Arikamedu have a striking similarity with others discovered at Oceo, a maritime city of Siam connected by canal to a port on the east coast of Siam. The trading station at Arikamedu flourished between 23 B.C. and 200 A.D., and towards the end of the period or a little later, Oceo commanded a large sea trade, preponderantly in imports from India brought over by Indians.[a] Sir Roland Braddell[b] also points out that merchants from India settled at Oceo, and it may not be unlikely that they came from the ports of India, as suggested by Prof. N. K. Sastri.

Taxila, situated at the head of Sind Sagar Doab between the Indus and the Jhelum rivers, was the meeting-place of three great trade routes: one from Hindustan and Eastern India, which has been described by Megasthenes as running from Pataliputra to the north-west of the Maurya Empire; the second from Western Asia through Bactria, Kapisa and Pushkalavati and so across the Indus at Ohind to Taxila; and the third from Kashmir and Central Asia by way of the Srinagar Valley and Baramula to Mansehra and so down to the Haripur Valley.[c]

The glass beads from Taxila are of great interest. Among them typical European beads from the settlements dating as far back as the fifth century B.C. or thereabouts are noticeable. This shows that European beads were reaching India before the time of Alexander and is another evidence of trade connections which must then have existed between Europe and Asia.[d] The most interesting beads are a series of eye-beads from Bhir Mound (a site in Taxila). These beads are virtually identical with those found around the Mediterranean and dating from the ninth to the third century B.C. From their close resemblance it appears that these beads were either actually made in the Mediterranean area or at least by men who came from that area or who had learnt how to make them from workmen who came from the Mediterranean countries.[e] Besides, glass beads of two strata (5th or 4th century B.C.) of Bhir Mound were of quite good quality and were coloured white, yellow, blue and green, with the blue ones relieved by white concentric circles in the familiar manner of Phoenician glass. About the segment glass beads of Bhir Mound, Beck is of the opinion that they have a great resemblance with Roman beads.

As to the later Sirkap collection, a considerable number of amber-coloured and grey beads of various shapes, and a still larger number of minute yellow and orange disks from the Śaka-Parthian settlements suggest that by the first century A.D. the local glass-makers had learnt how to produce these colours also. On the other hand, several of the beads of the rarer colours which appeared for the first time in the Śaka-Parthian period, notably cobalt, pale and peacock blue, cream, violet and blotched, were in all probability imported from the Mediterranean coast along with other glass vessels and many other objects. Beads, bangles and possibly a few other simple objects were produced at Taxila, but every one of the glass vessels so far unearthed was an import from Western Asia or the Mediterranean coasts. In view of the fact that the colours of the glasses used in these vessels (a fragment of a mosaic bowl, probably made in Campania, containing tesserae of eight different colours) are

[a] Sastri, 45. [b] Chakraborti, 131–33. [c] Marshall (3), 1–2.
[d] Beck (4), Introduction. [e] Beck (4), 20.

identical with those used in the beads—blue, green, jade, amber, amethyst, opal-white, etc., it is natural to conclude that the beads came from the same source as the vessels.[a]

Of the glass vessels or fragments of vessels found at Taxila, three complete conical flasks of sea-green colour were found at Sirkap. According to Marshall, all these glass vessels or the fragments were, without doubt, of foreign origin or nearly all date from the first century A.D. Small flasks of sea- or jade-green colour which have been well preserved are identical with those which were common throughout the Roman Empire during the early centuries of the Christian era.[b] Of two fragments of typical Roman blown flasks or bowls, one is rather translucent with a green tinge (with a specific gravity of 2.43) and the other is quite in its natural form apparently with some molten glass inside. A third one is the neck of an elaborately decorated bottle of a type found in Europe. The white pattern of the decoration seems to have been added on to a brown base, probably in the form of rings round the bottle before it was completely blown, the final design being produced partly by drawing on the surface with a wire and partly by blowing the glass. A specimen dating from the first century B.C. is a fragment of a very fine bowl. The method by which it seems to have been constructed was employed extensively by the Romans and many such specimens have been found at Pompeii and other sites. This technique was, at a later date, developed very extensively at Venice, and such glass was called *vitro di trina* or lace glass. Bowls of such glass were possibly made in several countries, but from the large quantities of fragments found in the Mediterranean area, it is probable that it originated in one of the countries bordering on that sea.

There are samples of various kinds of glass wares produced at places in the Mediterranean area. These wares were made with (a) lace glass or *vitro di trina*, (b) ribbed glass, (c) swirled or marbled glass, (d) blue and white cameo glass, (e) mosaic glass, (f) colourless and translucent glass, and (g) millefiori glass. All the glass vessels found on excavation at Taxila or at other sites in India and Afghanistan appear to be of foreign import. This is proved by the fact that at Begram (ancient Kapisa in Afghanistan), M. Hackim has recently unearthed a surprisingly rich collection of glass wares almost all of which were imported from Syria or other places around the Mediterranean coast.[c] These bowls are known to have originated in Italy and spread throughout the Roman world during the first century B.C. and the end of the first century A.D. They were very common, particularly at Haltern in Germany.[d] At Taxila, these vessels were imported by both land and sea routes through the ports of Western India, as mentioned in the *Periplus*.

In the period between the second century B.C. and the second century A.D. there was a gradual infiltration of foreigners like the Romans and Ionian Greeks into India by sea through Broach on the western coast and through Arikamedu on the eastern coast. Excavations at sites like Paithan, Ter, Nevasa, Kondapur and Kolhapur (within the Sātavāhana Empire) have yielded specimens of Roman glass wares providing evidence of India's cultural contact with the Roman world.[e]

Indian glass beads have been found at a number of places in East Africa on the

[a] Marshall (3), 2, 685. [b] Marshall (3), 2, 685–86. [c] Marshall (3), 2, 688–89.
[d] Wheeler *et al.*, 102. [e] Chakraborti, 282–83.

west as well as at places in Japan, Sumatra, Java and the Malay Peninsula. This shows that India had trade connections with those countries even in early days. These Indian glass beads, found in East Africa, Japan and Malay Peninsula, are generally known as trade-wind beads because they were used as medium of exchange in those days.[a] The Indian coastal ports which became the centres of these trade-wind beads were Kolhapur (Brahmapuri), Negapatam (on eastern coast), Arikamedu (near Pondicherry), Ahicchatra, Cambay, Coimbator, etc. Two types of such beads, namely multiple wound beads of opaque glass and drawn beads of opaque glass, have been found at Zanzibar. It is supposed that all these beads had been brought in by the Arabs, Persians, Indians or Chinese, and Portuguese who came to East Africa.

During the eleventh century A.D. three embassies were sent to China by three Chola monarchs—Rajaraja I (1015 A.D.), Rajendra I (1033 A.D.) and Kulottanga I (1077 A.D.), and an account of these embassies has been recorded in the Chinese annals, especially in the *Chan-Ju-kua*. Of these, the embassy sent by Kulottanga I was the most notable. It consisted of as many as seventy-two men and the articles they carried with them included glass objects[b] in addition to other specimens.

[a] Van Der Sleen, 203–16. [b] Dikshit, 157ff; Gode (1), 82–88.

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ACK	*Abhidhāna Cintāmaṇi-Kośa* by Hemachandra. Edited in Devenand Lalbhai Jaina Series, Surat, 1946.
Mā. ull	*Abhilasitārtha-Cintāmani* or *Mānasollasa* by King Someshwara. Edited in Mysore (in full); edited (partly) in Gaekward Oriental Series, **28**, Pt. 1, 1–3.
Ā. Sū	*Āchārаṅga Sūtra* with a commentary of Śilaṅka, Surat, 1935; *Sacred Books of the East*, **22**, Pt. 1.
AM	*Agasti-Mata* by Agastya. Edited by Finot, in *Les Lapidaries Indiens*.
Amara	*Amarakoṣa* by Amarasimha. Edited by Panshikar, Nirnaya-Sagar Press, 3rd edition (Bombay), 1905.
AT	*Anekārtha-Tilaka* by Mahipa. Edited by M. M. Patkar, Deccan College, Poona, 1947.
AŚ	*Arthaśāstra* by Kauṭilya. Edited and translated by R. Shama Sastri, Mysore, Oriental Library, 1909.
BŚ	*Bhallaṭa-Śataka* by Bhallata. Edited in *Kavyamala*, Guchchha IV.
Bṛh. S	*Bṛhat-Saṃhitā* by Varahamihira. Edited by Kern, in *Bibliotheca Indica*, 1865. Translated by V. Subrahmanya Sastri, Bangalore, 1947.
CS	*Caraka Saṃhitā* by Caraka. Edited by Jivananda Vidyasagar, Calcutta, 1896.
CS. Ci	*Caraka Saṃhitā Cikitsā-sthāna.*
CV	*Culla-Vagga: Sacred Books of the East*, **20** (from Vinaya Pitaka).
DNM	*Deśi-nāma-mālā* by Hemachandra. Edited by Maralyadhar Banerjee, Calcutta, 1931.
DV	*Divyāvadāna.* Edited by Cowell and Neil, Cambridge, 1886 (in Roman character). Edited by P. L. Vaidya, Darbhanga, 1959 (in Devanagari character).
Gḍ. P.	*Garuḍa Purāṇa.*
GV	*Gauḍa-vaho* by Vakpati, Bombay Sanskrit and Prakrit Series, Poona, 1927.
HK	*Halāyudha-koṣa* by Halayudha. Edited by Jayasankar Joshi, Saraswati Bhavan, Varanasi, Saka 1879.
HP	*Hitopadeśa* by Narayana Pandita, Nirnaya-Sagar Press, 14th edition, Bombay, 1947.
KKS	*Kapiṣṭhala-kaṭha Saṃhitā.* Edited by Raghuvira (Meherchand Lachhman Das Sanskrit and Prakrit Series, Lahore), 1932.
KSS	*Kathā-Sarita-Sāgara* by Somadeva. Edited in Nirnaya-Sagar Press, Bombay, 1930. Trans. by Penzer, *Ocean of Story*, 7 vols.

Kr. R — *Kritya-Ratnākara* by Chandeshwara Thakkura. Edited by Kamala Krishna, in *Bibliotheca Indica*, No. 287, Calcutta, 1925.

KM — *Kuṭṭanimata* by Damodara. Edited by Parab, in *Kavyamala*, Guchchha 3.

MB — *Mahābhārata.*

MV — *Mahā-Vagga: Sacred Books of the East*, **17**, Oxford, 1882 (from Vinaya Pitaka).

MK — *Medini-Kośa* by Medini. Edited under *Kosanam Samuccaya* (lithograph, n.d.).

NRP — *Nava-Ratna-Parīkṣā* by Narayana. Edited by Finot, in *Les Lapidaires Indiens.*

NSK — *Nītisāra* by Kāmandaka, Venkatesvara Press edition, Bombay, Saka 1826.

Rājt — *Rājataraṅginī* by Kalhana, Edited by Stein, Srinagar-Kashmir State Council, 1892.

Rām — *Rāmāyaṇa.* Edited with commentary, in *Rāmāyaṇatilaka* by H. C. Bhattacharya, 7 vols., Calcutta, 1869–86.

RPS — *Rasa-Prakāśa Sudhākara* by Yasodhara. Edited by J. K. Sastri, Gondal, 1940.

RRNi — *Rasa-Ratnākara* by Nityanatha Siddha. Edited by J. K. Sastri, Gondal, 1940.

RRS — *Rasaratnasamuccaya* of *Vāghbhaṭa*, Poona, 1890.

RṇV — *Rasārṇava.* Edited by P. C. Ray and Harish Chandra Kaviratna, in *Bibliotheca Indica*, Calcutta, 1910.

RPBu — *Ratna-Parīkṣā* by Buddhabhata. Edited by Finot, in *Les Lapidaires Indiens.*

RPTh — *Ratna-Parīkṣā* by Thakkar Pheru. Edited by Agarchand and Bhavarla Nahta, Bikaneer, 1961.

Śat. Br. — *Śatapatha Brāhmana.* Edited by Chandradhara Sarma, in *Achyuta Granthamala*, Series No. 11 & 12, Benares, 1938–41.

ŚN — *Śukranītisāra.*

SS — *Suśruta Saṃhitā.* Translated into English by Kunjalal Bhishagratna, 3 vols., Calcutta, 1907–15; 2nd ed., Chowkhamba Sanskrit Series Office, Varanasi, 1963.

SS. Sū — *Suśruta Saṃhitā Sūtrasthāna.*

Taitt. Br. — *Taittirīya Brāhmana* with commentary *Vedārtha Prakāśa* by Sayanacarya. Edited by Rajendra Lal Mitra, *Bibliotheca Indica*, Series No. 31, 1890, Calcutta.

Taitt. S — *Taittirīya Saṃhitā.*

Trik. S — *Trikaṇḍaśeṣa* by Purushottama, in *Dvadasa Kosa Samgraha*, Benaras, 1873.

VC — *Vyāsayogi-carita.* Edited by B. Venkoba Rao, Bangalore, 1926.

YK — *Yukti-Kalpataru* by Bhoja. Edited by Isvara Chandra Sastri, Calcutta Oriental Series, Calcutta, 1917.

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group, and Islamic lead glass. Indian glass samples do not appear to fit in with any of these categories, and probably followed a tradition of its own.

The book discusses all this and many more. Glass objects found in India from various archaeological sites have been discussed in detail. Available scientific studies and physico-chemical analyses have been critically examined to gain insight into the manufacturing processes and raw materials employed. The study has been further enriched by a discussion of the furnaces, tools and techniques of fashioning glass objects, used in the industry. No less important is the account of Indian glass as an article of trade in ancient and medieval times.